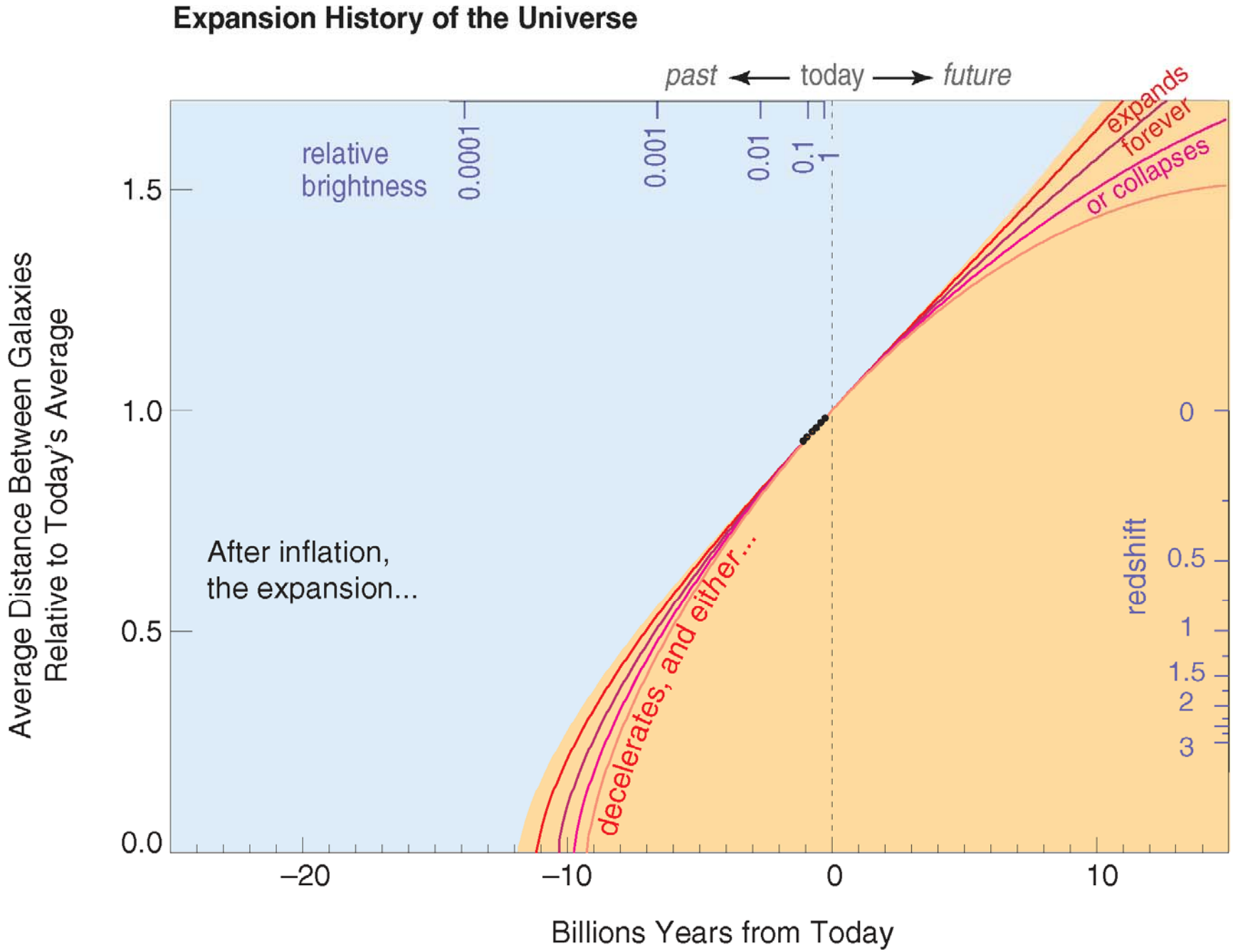
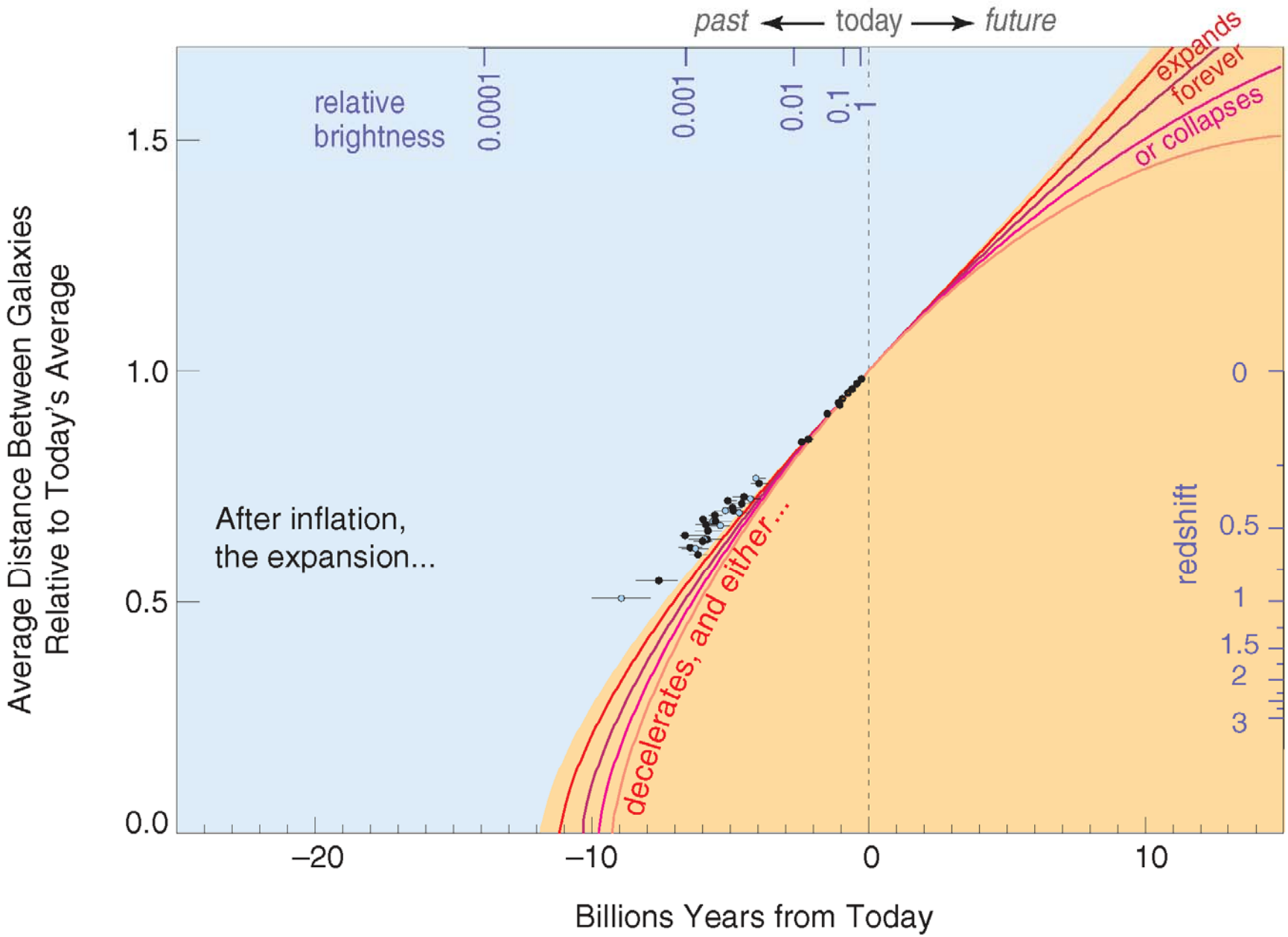
Physics Division Director's Review:
Supernova Cosmology Program

Saul Perlmutter
November 2004


Expansion History of the Universe
past
today
future
relative brightness
0.0001
0.001
0.01
0.1
1
expands forever or collapses
After inflation, the expansion...
decelerates, and either...
redshift
0
0.5
1
1.5
2
3
Average Distance Between Galaxies Relative to Today's Average
0.0
0.5
1.0
1.5
–20
–10
0
10
Billions Years from Today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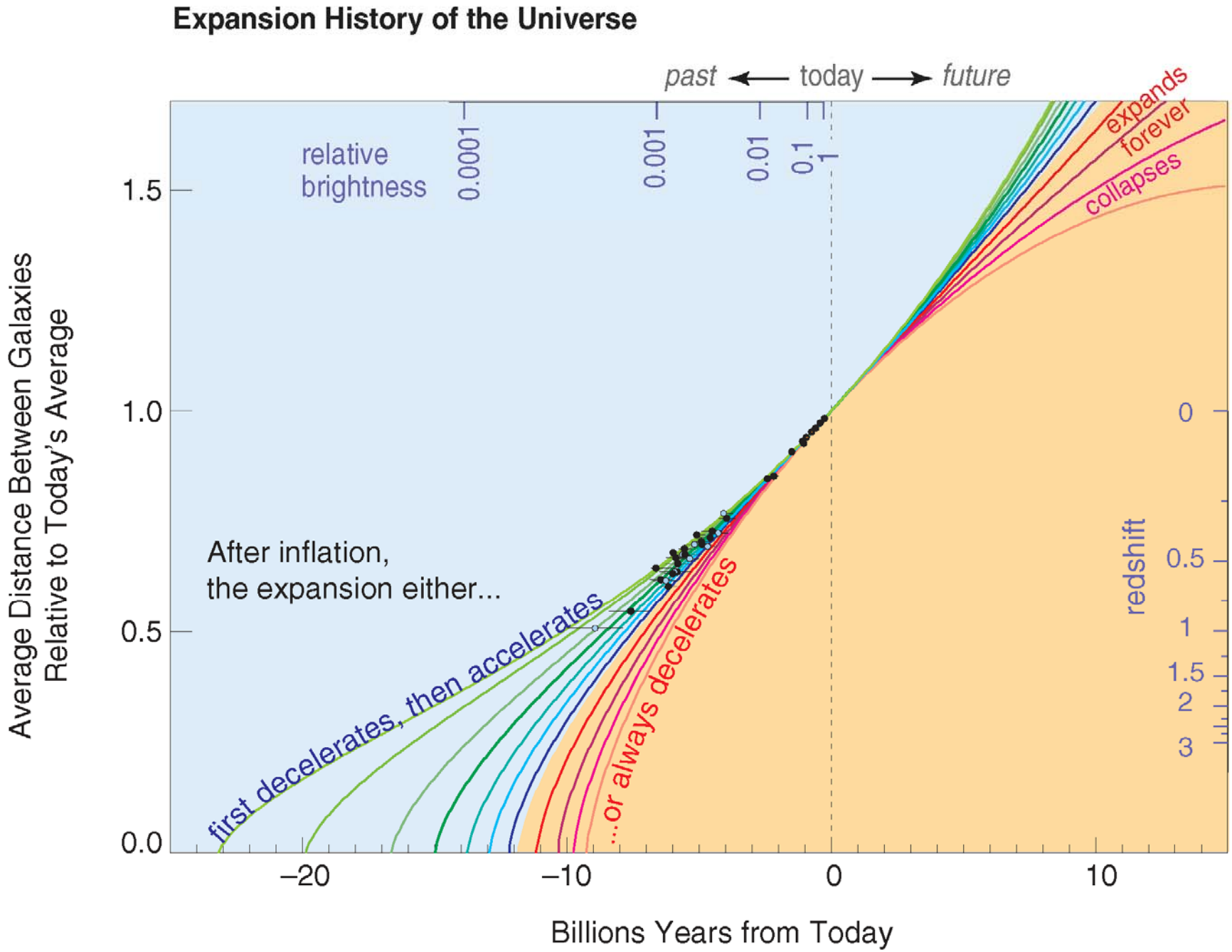
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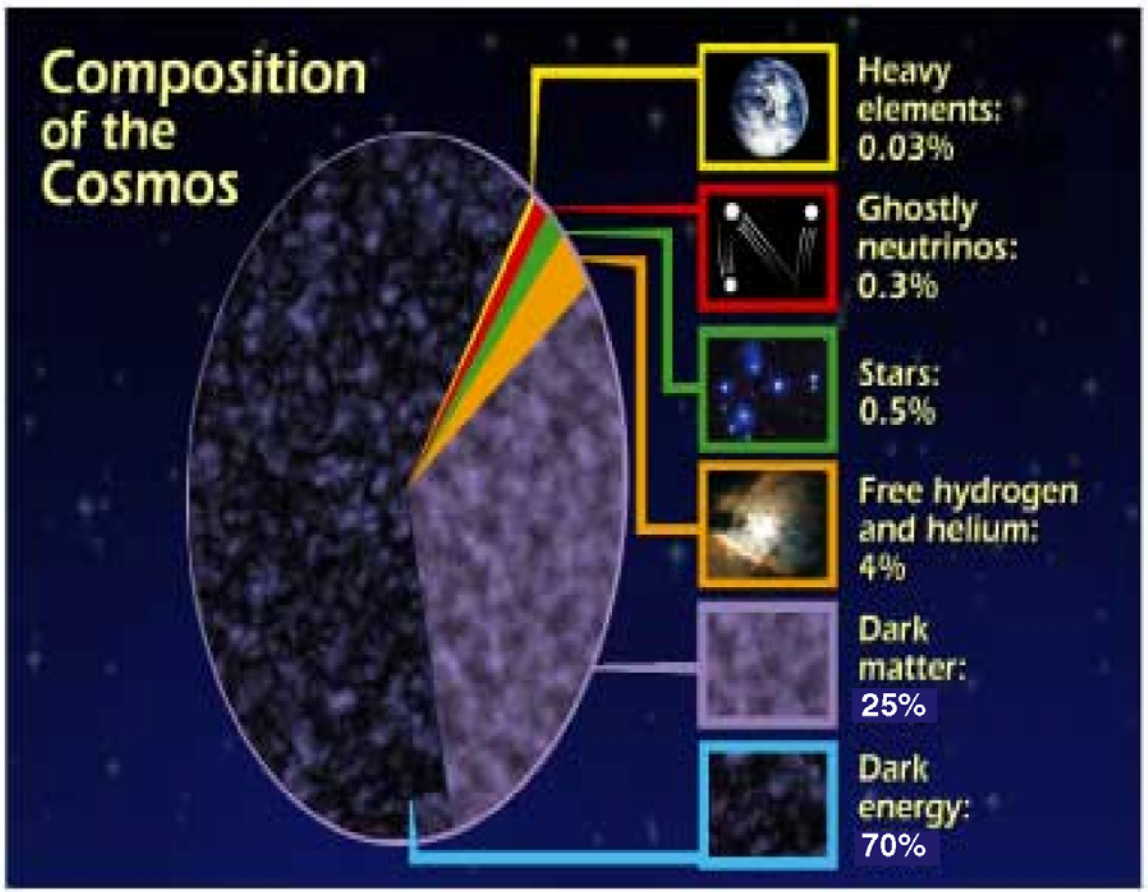
Physicists on Vacuum Energy/Cosmological Constant:

"Right now, not only for cosmology but for elementary particle theory, this is the bone in our throat."

—Steven Weinberg

"...Maybe the most fundamentally mysterious thing in basic science."

—Frank Wilczek



"...Would be No. 1 on my list of things to figure out."

—Edward Witten

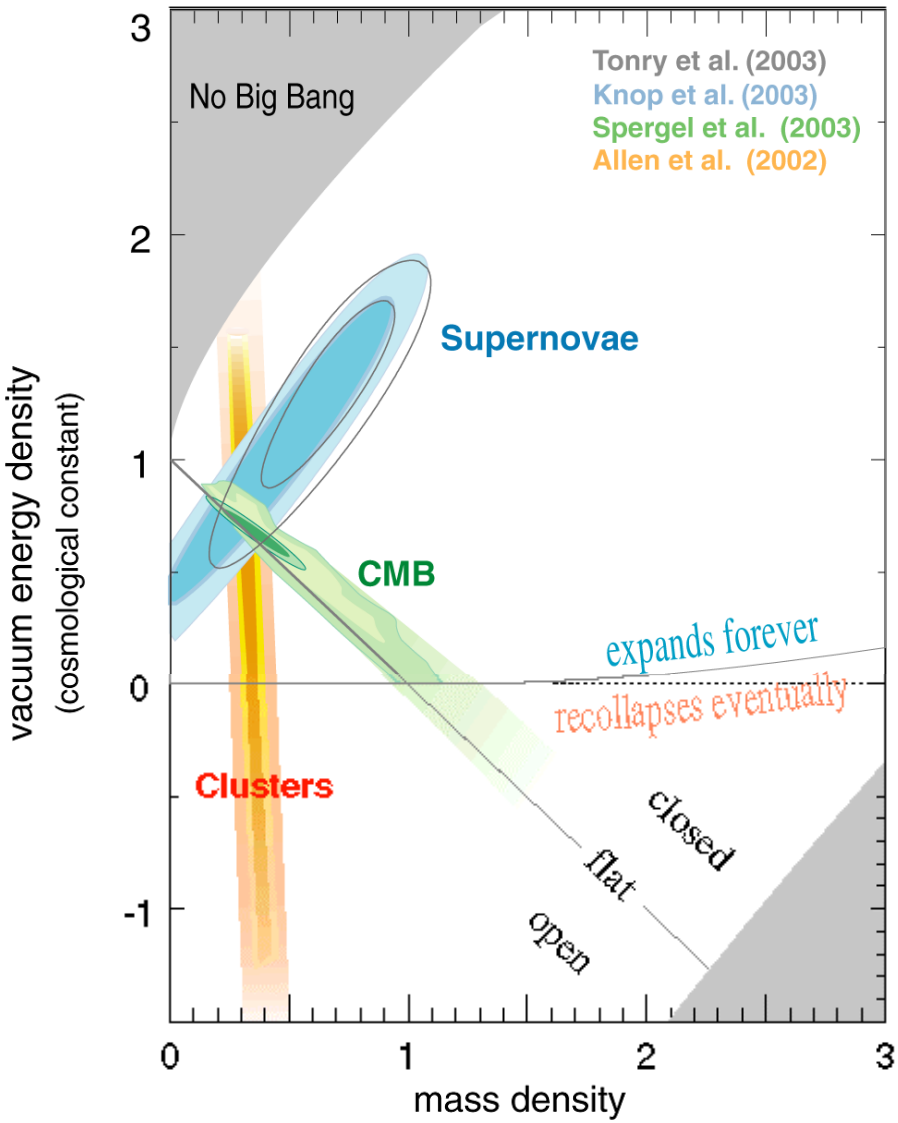
"Basically, people don't have a clue as to how to solve this problem."

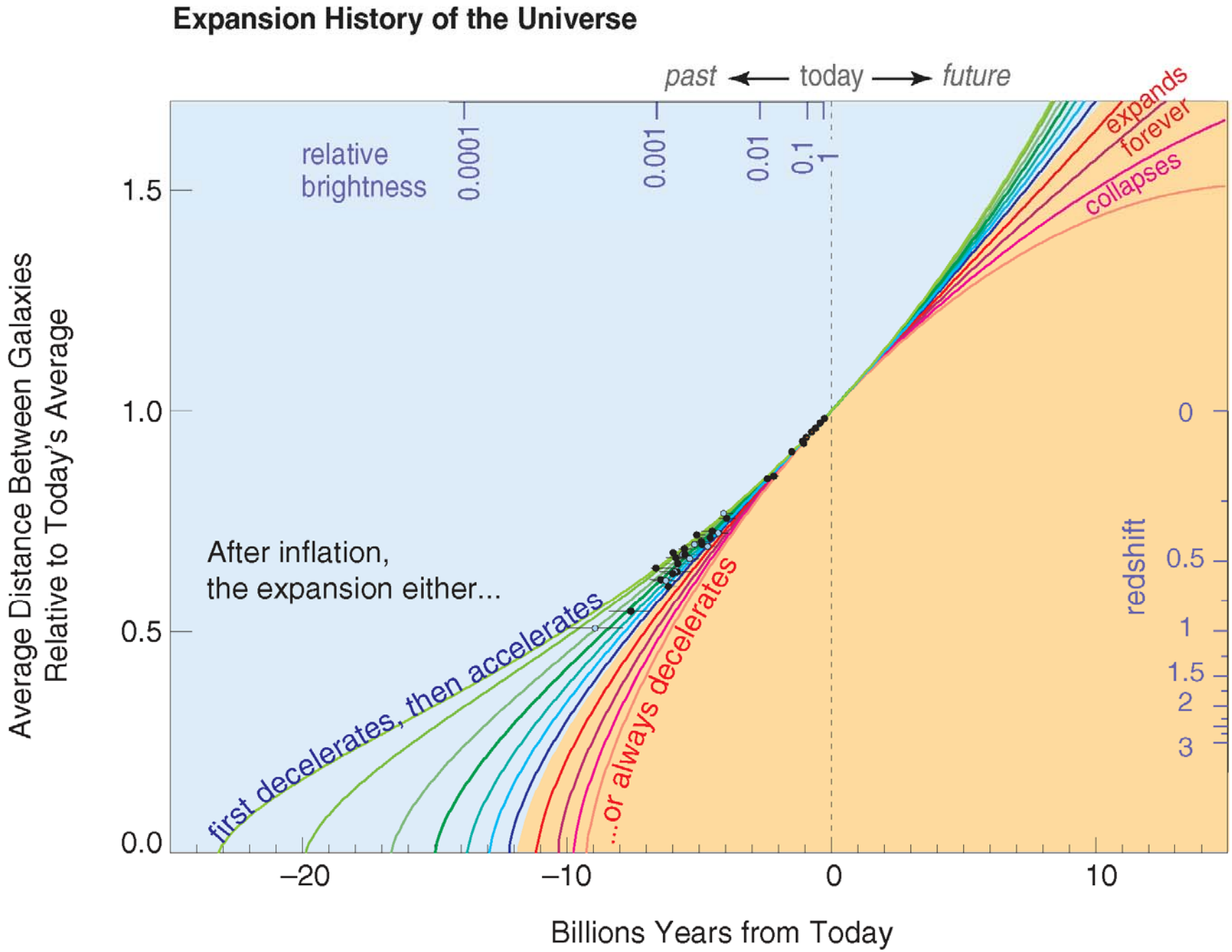
—Jeff Harvey

"This is the biggest embarrassment in theoretical physics,"

—Michael Turner

Narrowing in on Cosmological Parameters

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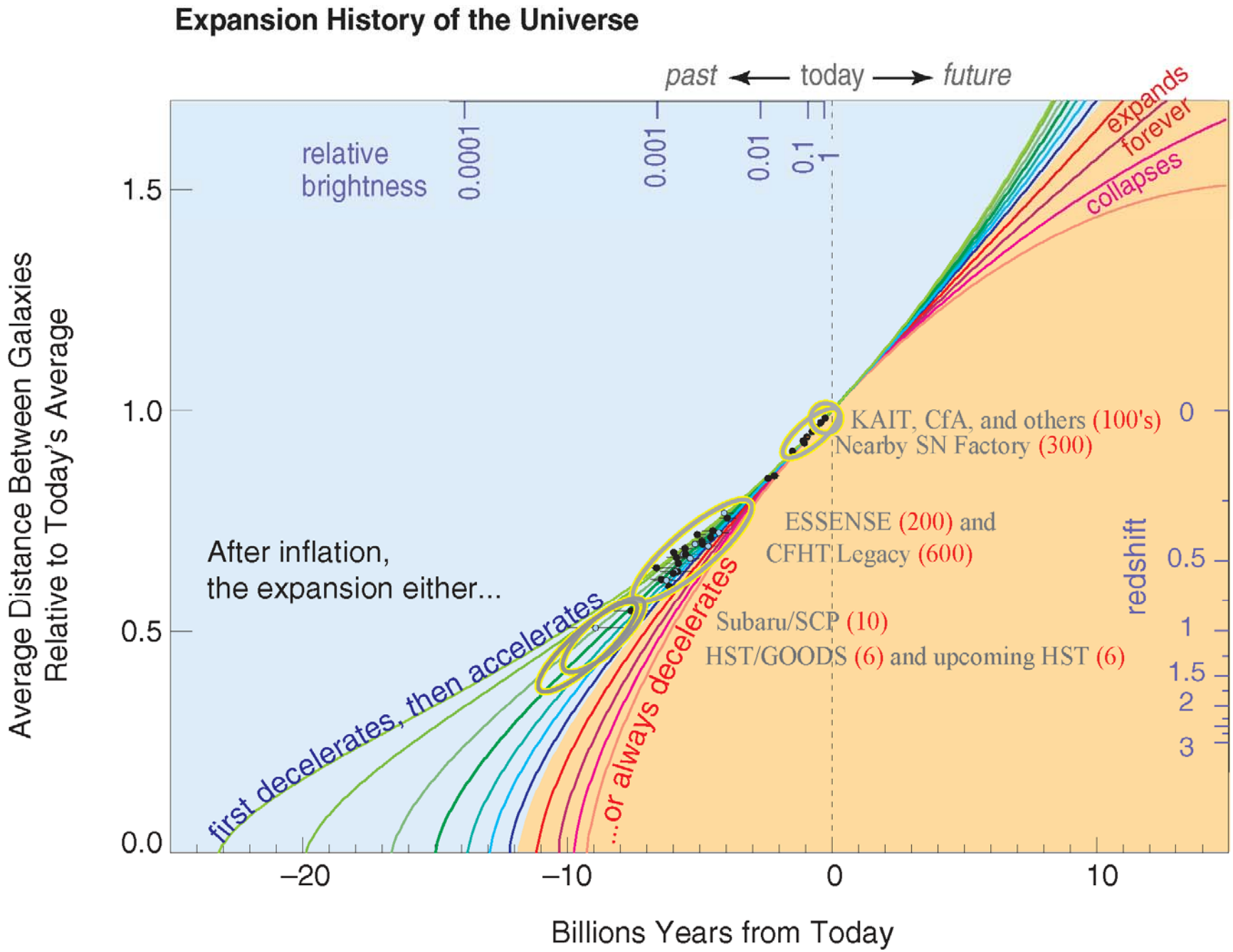
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KAIT, CfA, and others (100's)
Nearby SN Factory (300)
ESSENSE (200) and
CFHT Legacy (600)
Subaru/SCP (10)
HST/GOODS (6) and upcoming HST (6)
redshift
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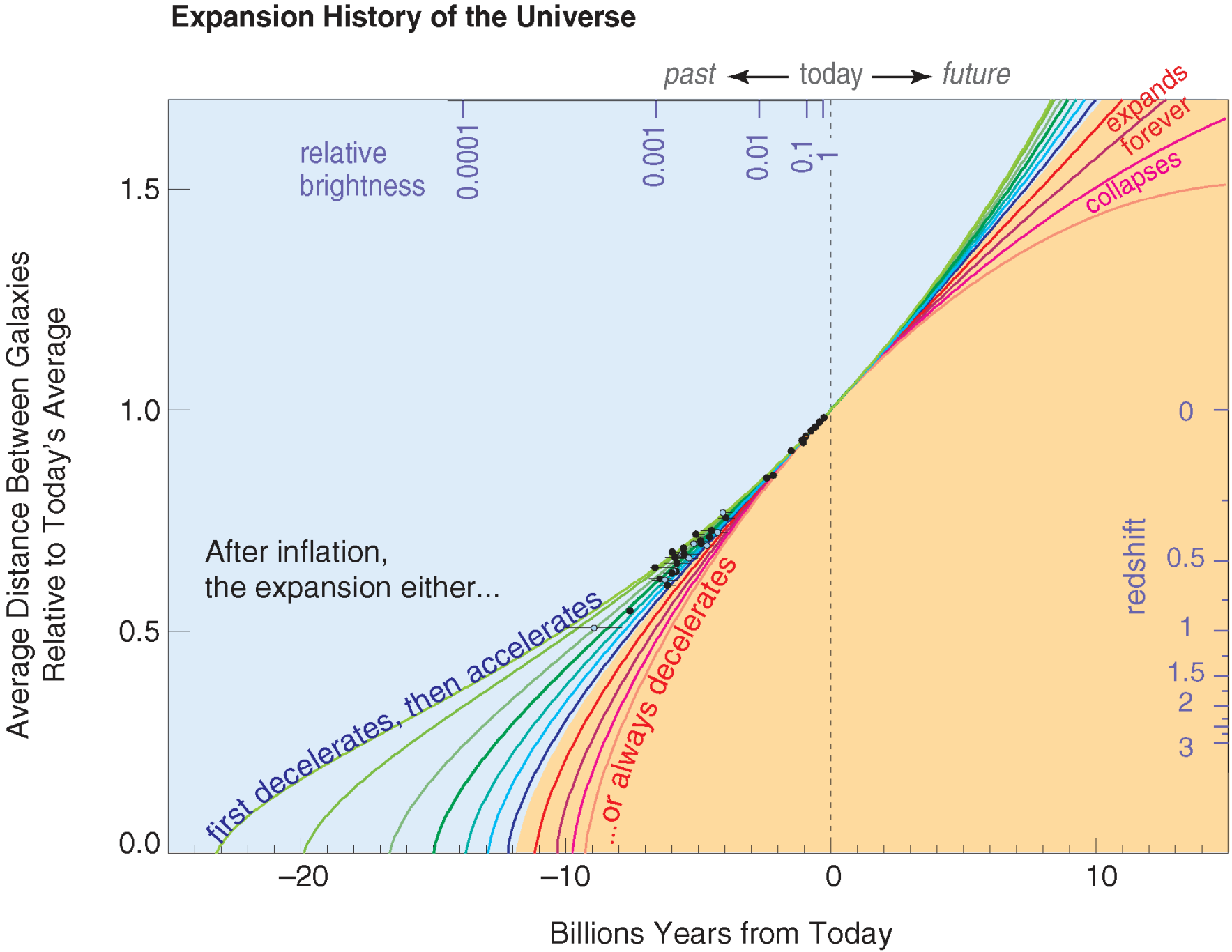
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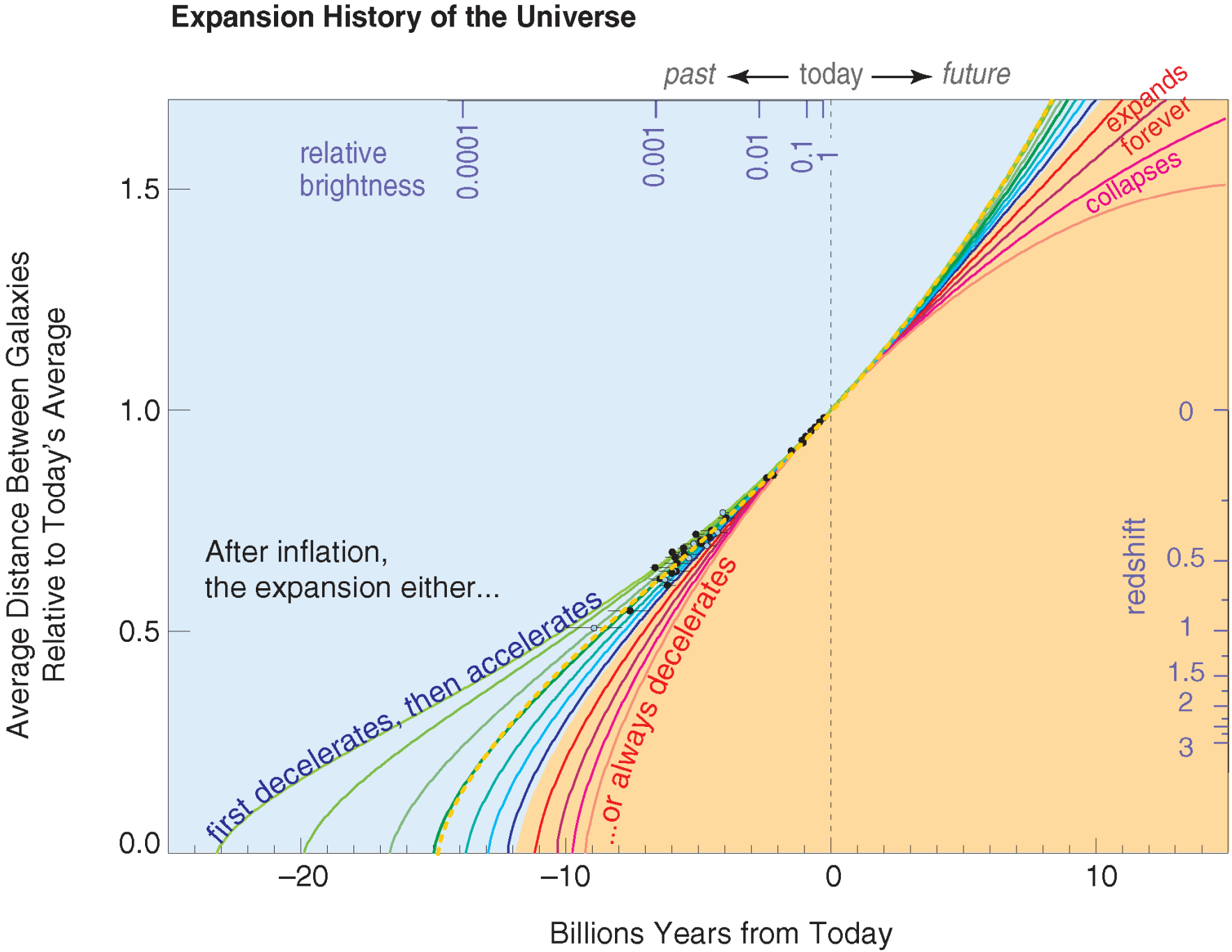
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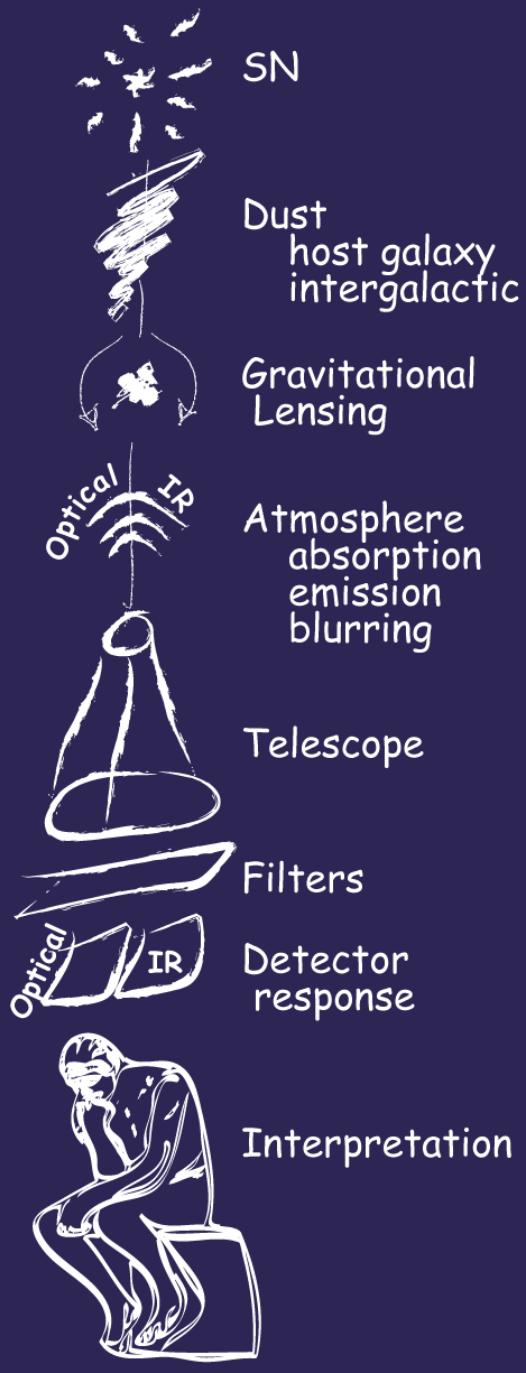
A Really Hard Goal:

A measurement of the expansion history of the universe with enough accuracy that a measurement of a *change* in the properties of the dark energy would be trusted.


SN
Dust
host galaxy
intergalactic
Gravitational
Lensing
Optical
IR
Atmosphere
absorption
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Telescope
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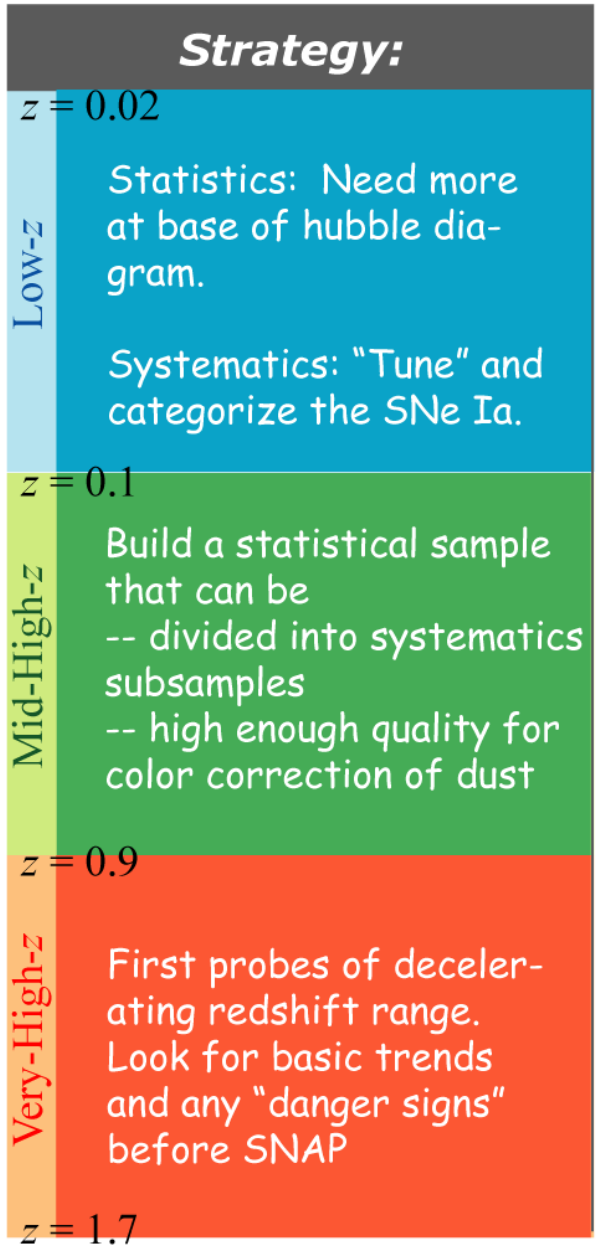
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z = 0.02
Low-z
Statistics: Need more at base of hubble diagram.
Systematics: "Tune" and categorize the SNe Ia.
z = 0.1
Mid-High-z
Build a statistical sample that can be
-- divided into systematics subsamples
-- high enough quality for color correction of dust
z = 0.9
Very-High-z
First probes of decelerating redshift range.
Look for basic trends and any "danger signs" before SNAP
z = 1.7

Supernova Cosmology at LBNL
2004

G. Aldering* # †
S. Bailey†
C. Bebek†
M. Bester† (SSL)
W. Carithers†
W. Chickering#
E. Commins*
A. Conley*
K. Dawson†
C. Day†
R. DiGennaro†
V. Fadeyev*
J. Fairfield†
B. Farris*
K. Garg#
D. Gerdes†(UM)
G. Goldhaber*
D. Groom*
J. Guedes#
H. Heetderks†
M. Hoff†
S. Holland†
P. Jelinsky† (SSL)
A. Karcher†
A. Kim†
W. Kolbe†
M. Kowalski*
W. Kramer†
B. Krieger†
A. Kulkarni#
G. Kushner†
N. Kuznetsova†
R. Lafever†
J. Lamoureux†
M. Lampton† (SSL)
S. Lau*
F. Lau#
B. Lee#
M. Levi†
E. Linder†
S. Loken# †
B. McGinnis†
R. Miguel†
P. Nugent* # †
N. Palaio†
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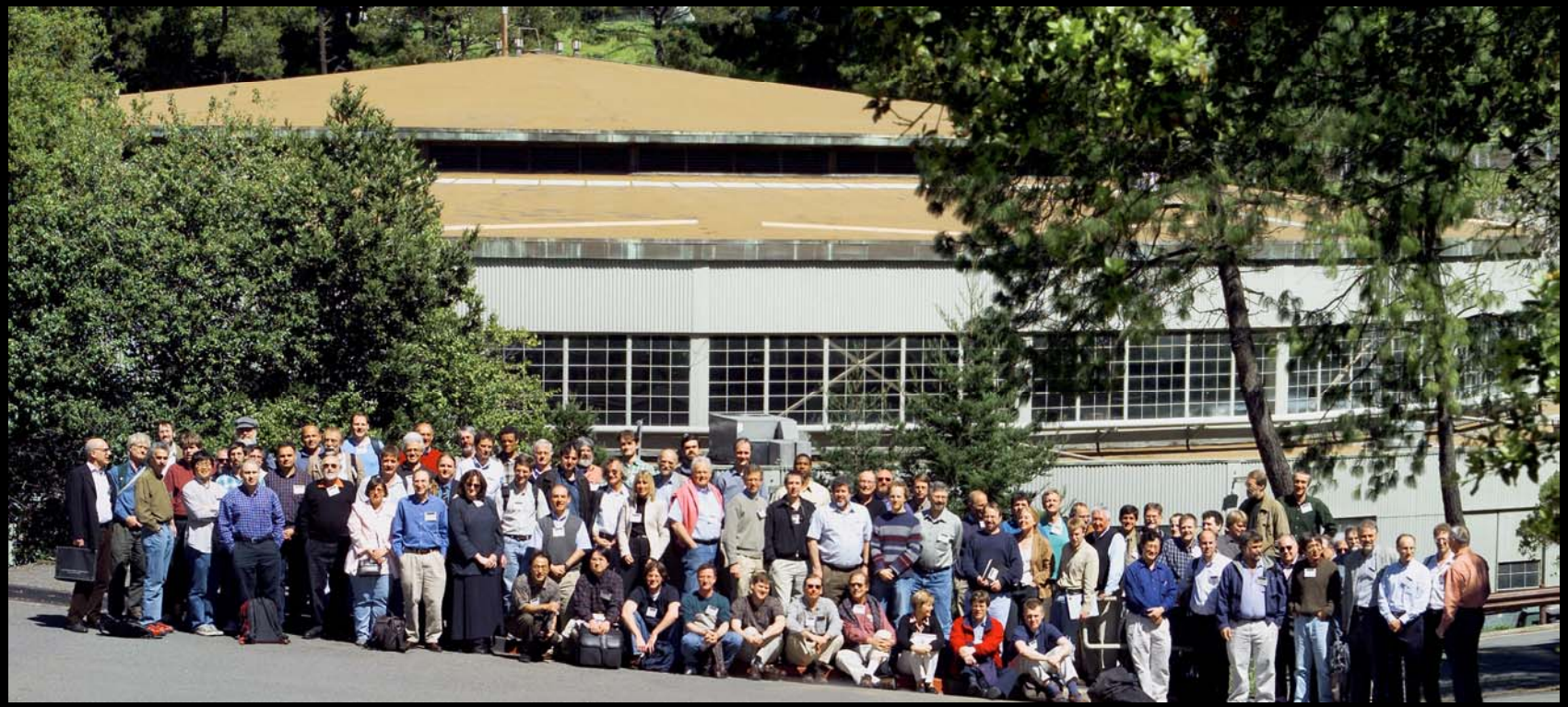
C. Pennypacker*
S. Perlmutter* # †
N. Roe* †
D. Schlegel* #
R. Scalzo#
M. Sholl† (SSL)
J. Siegrist#
G. Smoot†
A. Spadafora* †
M. Strovink*
R. Thomas* #
H. Von Der Lippe†
J-P.Walder†
L. Wang* #
G. Wang†

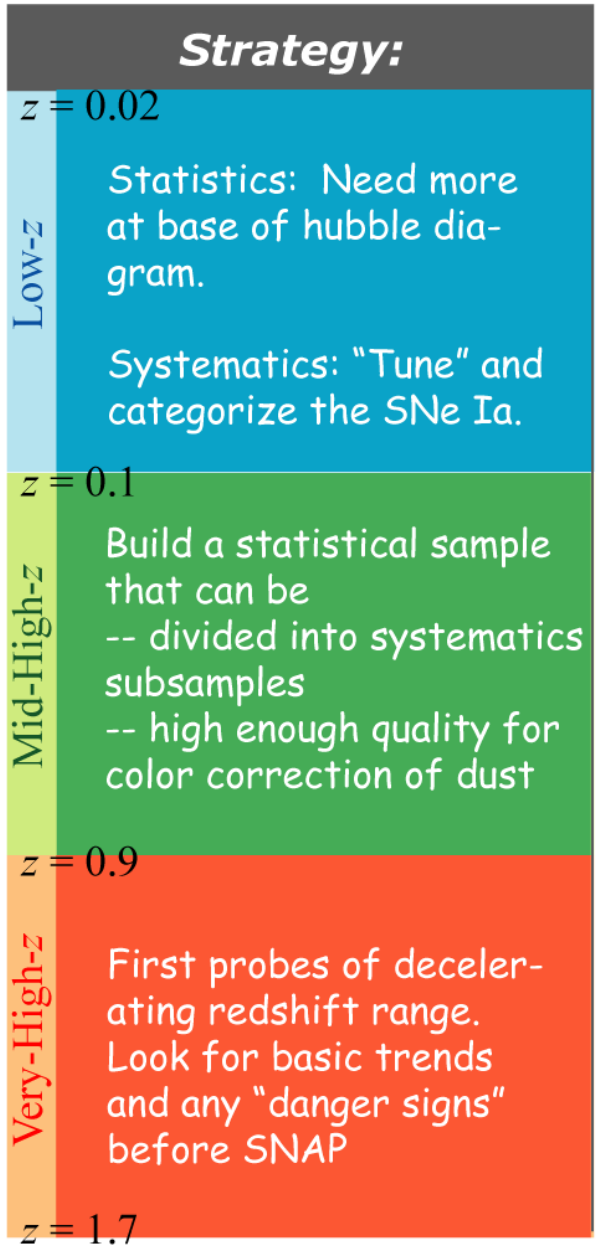
faculty
Staff
postdoc
student

SCP *
SNF #
SNAP †

Supernova Cosmology Project Team
(1997)



SuperNova/Acceleration Probe (SNAP)
Collaboration Team (2004)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z = 0.9
Very-High-z
First probes of decelerating redshift range.
Look for basic trends and any "danger signs" before SNAP
z = 1.7

Strategy:	Analyzing:	Running:	Planning:
Low-z ($z = 0.02$) Statistics: Need more at base of hubble diagram. Systematics: "Tune" and categorize the SNe Ia.	SCP Spring 99 data set: Spectroscopy papers Lightcurves Literature data: CMAGIC	Nearby SN factory commissioning collecting data	SN factory upgrades?
Mid-High-z ($z = 0.1$) Build a statistical sample that can be -- divided into systematics subsamples -- high enough quality for color correction of dust	SCP+Literature data: "Blinded" CMAGIC	SN Legacy Survey: first results	Dark Energy Survey SNAP
Very-High-z ($z = 0.9$ – $z = 1.7$) First probes of decelerating redshift range. Look for basic trends and any "danger signs" before SNAP	"Albinoni": first decelerating SN A complete data set: CFHT/CTIO --> HST Subaru --> HST	HST search: highest-z discoveries	HST search 2? SNAP

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Moore Foundation Grant

- Total funding is $2.4M over three years to SSL and LBNL (through subcontract). PI's: Perlmutter & Levi
- Moore proposal is incremental and assumes that SNfactory puts data on disk
- Proposal call for very specific deliverables to enhance the usefulness of the SNfactory dataset.

  "Outcomes:"

  - #1: The Nearby Supernova Factory Project will significantly improve their understanding of Type Ia supernovae as distance indicators.
  - #2: The Published study of the Nearby Supernova Catalog becomes a definitive resource for measurements of dark energy and will reduce the uncertainty in the dark energy equation of state.

Moore Outcome 1

Outcome: The Nearby Supernova Factory Project will significantly improve their understanding of Type Ia supernovae as distance indicators.

Activity #	*Output*	*Activity*	*Target Date*	
1A	**Prototype Data Catalog**	**Requirements Analysis and Documentation** **Prototype Implementation** **Testing** **Document**	**October 2005**	
1B	**Long-term Scheduler**	**Requirements Analysis** **Implement Prototype** **PerformanceTesting** **Refine Survey Coverage**	**June 2005**	
1C	**Publications on Type Ia Supernovae**	**Data Analysis** **Draft Paper** **Review/Edit** **Publish**	**December 2005 – September 2007**	
1D	**Publication on Calibration Procedure**	**Define Calibration Procedures** **Document Procedures** **Apply Calibration** **Draft Paper** **Review/Edit** **Publish**	**March 2007 September 2007**	

Moore Outcome 2

Outcome: The Published study of the Nearby Supernova Catalog becomes a definitive resource for measurements of dark energy and will reduce the uncertainty in the dark energy equation of state.				
Activity #	***Output***	***Activity***	***Target Date***	
2A	**Requirements Document for Data Catalog**	**Requirements Analysis** **Draft Document** **Review with users** **Finalize Requirements**	**June 2006**	
2B	**Schema definition for extensions to support new users**	**Draft Schema** **Review** **Implement Schema**	**September 2006**	
2C	**Operational Data Catalog**	**Implement** **Test** **User Documentation**	**June 2007**	
2D	**Publication on Measurements of Dark Energy**	**Draft Paper** **Review/edit** **Publication**	**October 2007**	

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SN

Dust
host galaxy
intergalactic

Gravitational
Lensing

Atmosphere
absorption
emission
blurring

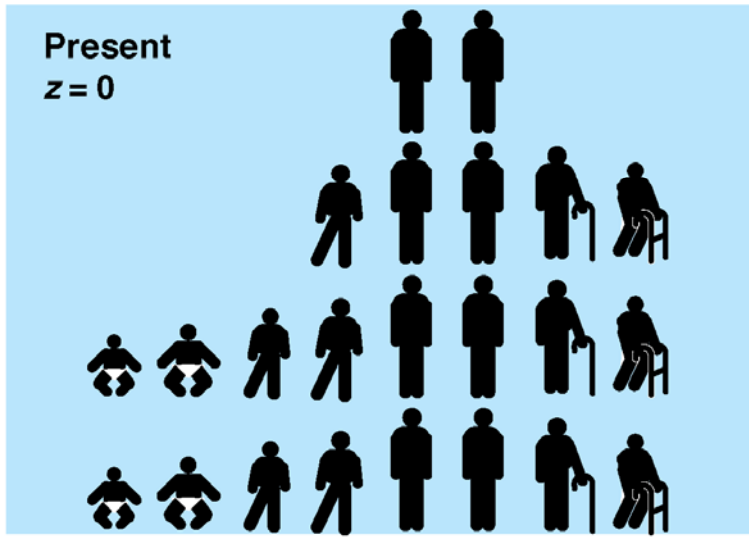
Telescope

Filters

Detector
response

Interpretation

Supernova Demographics

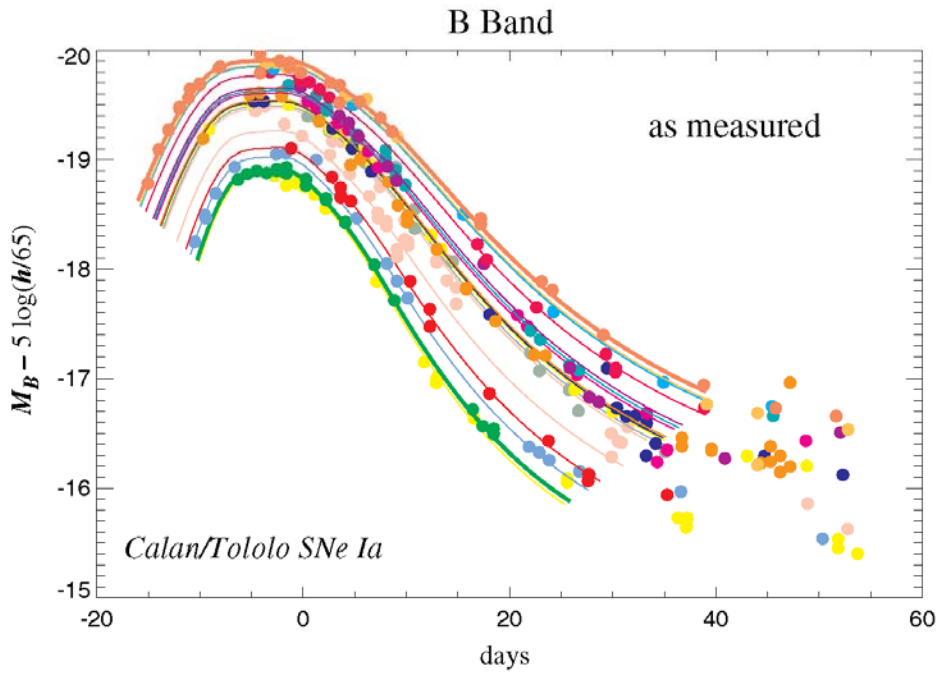


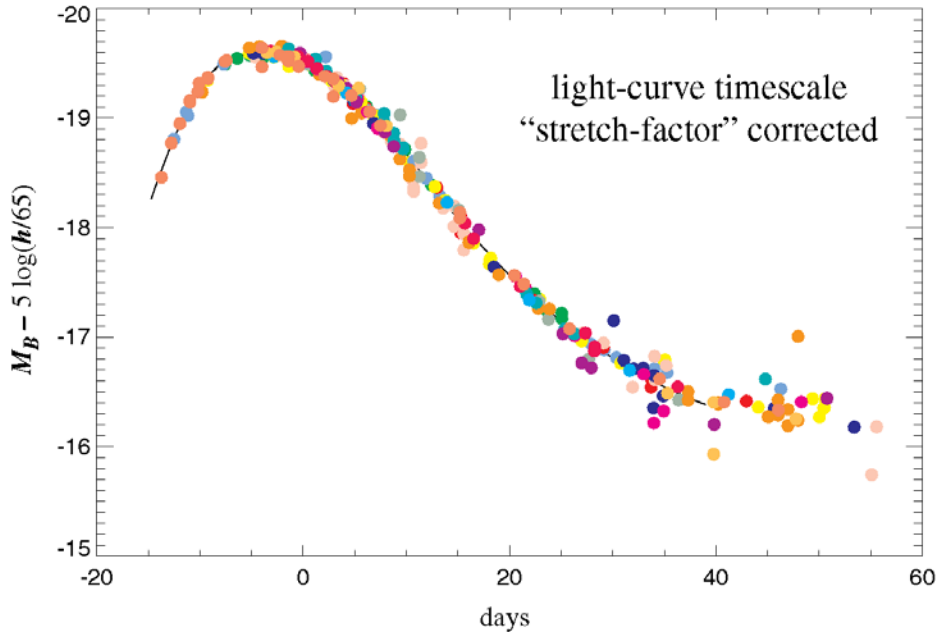
Galaxy Environment Age

← Younger

Older →


SN
Dust
Lensing
Optical
IR
Atmosphere
Filters
Optical
IR
Detectors
Interpretation


B Band
as measured
Calan/Tololo SNe Ia
$M_B - 5\log(h/65)$
days
-20
-19
-18
-17
-16
-15
-20
0
20
40
60


light-curve timescale
"stretch-factor" corrected
$M_B - 5\log(h/65)$
days
-20
-19
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0
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SN

Dust

Lensing

Optical IR

Atmosphere

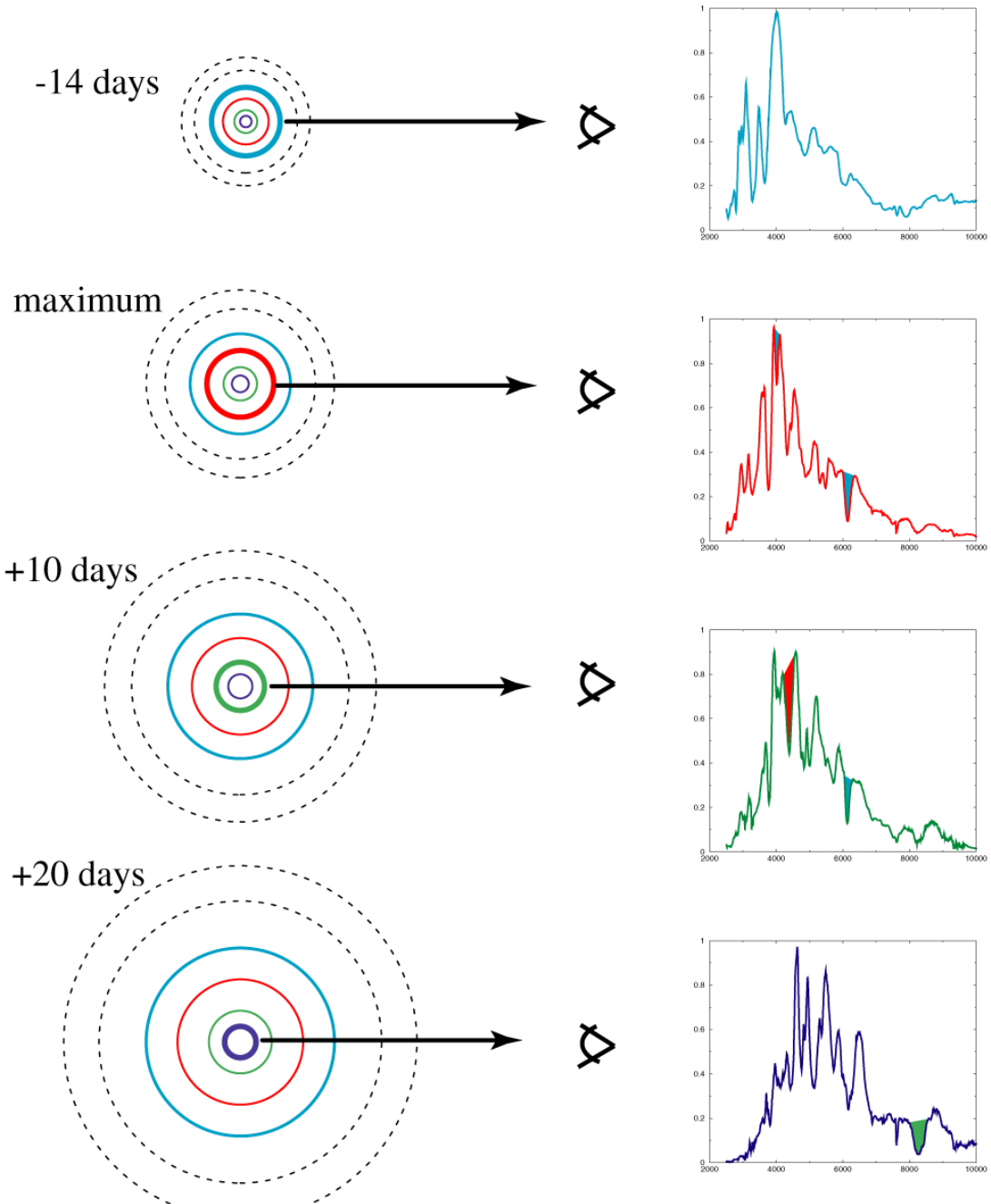
Filters

Optical IR

Detectors

Interpretation

The Time Series of Spectra is a "CAT Scan" of the Supernova

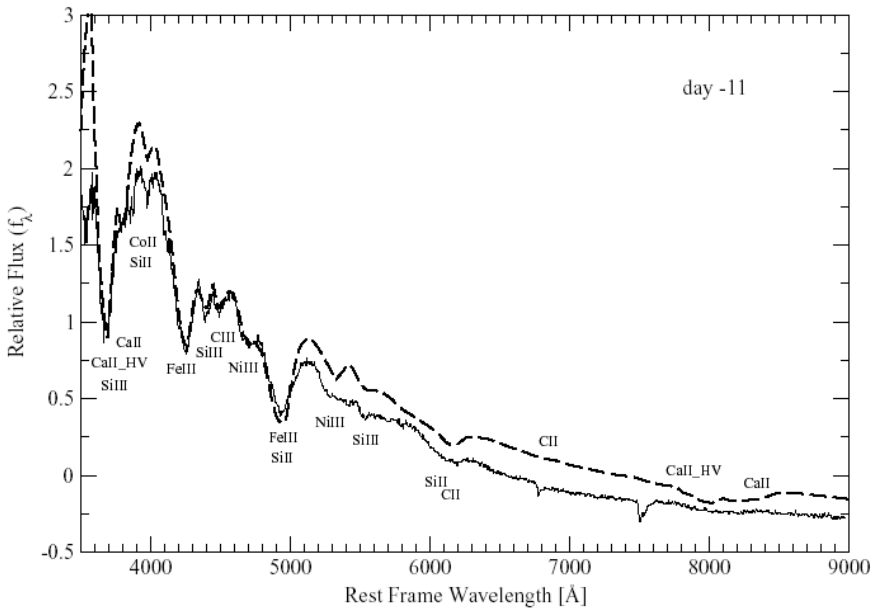


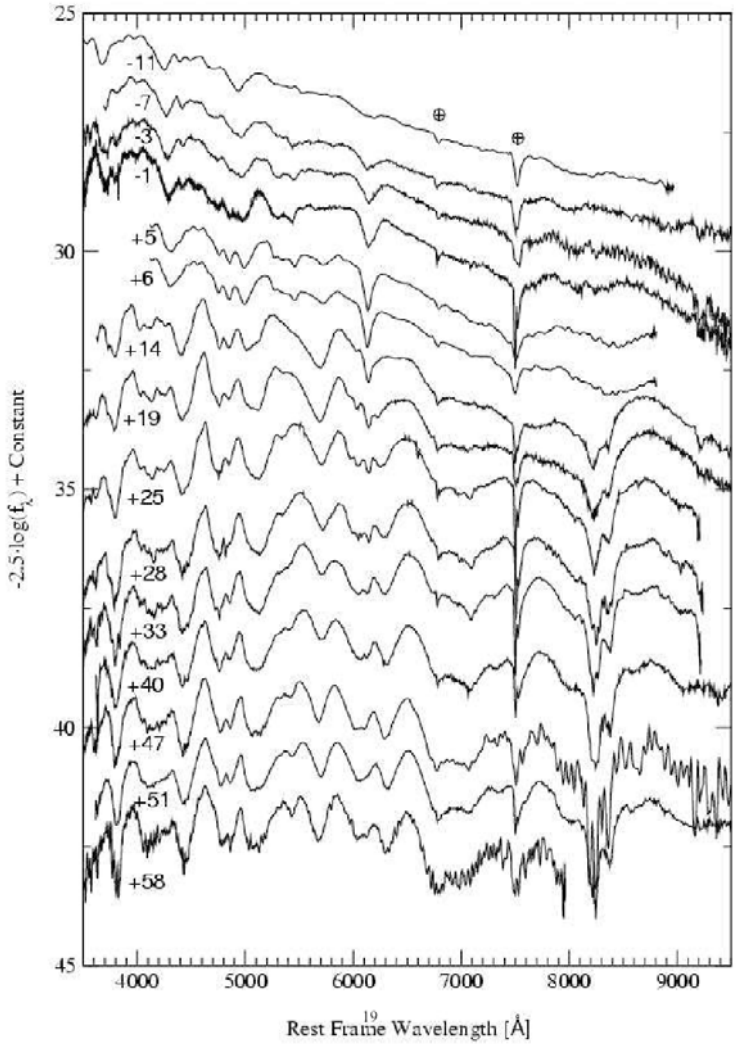
Recent Publications (1)

Spectroscopic Observations and Analysis of the Peculiar SN 1999aa

G. Garavini *et al.*, AJ 128, 387 (July 2004)

High S/N spectra allow for identification and temporal evolution of intermediate mass elements





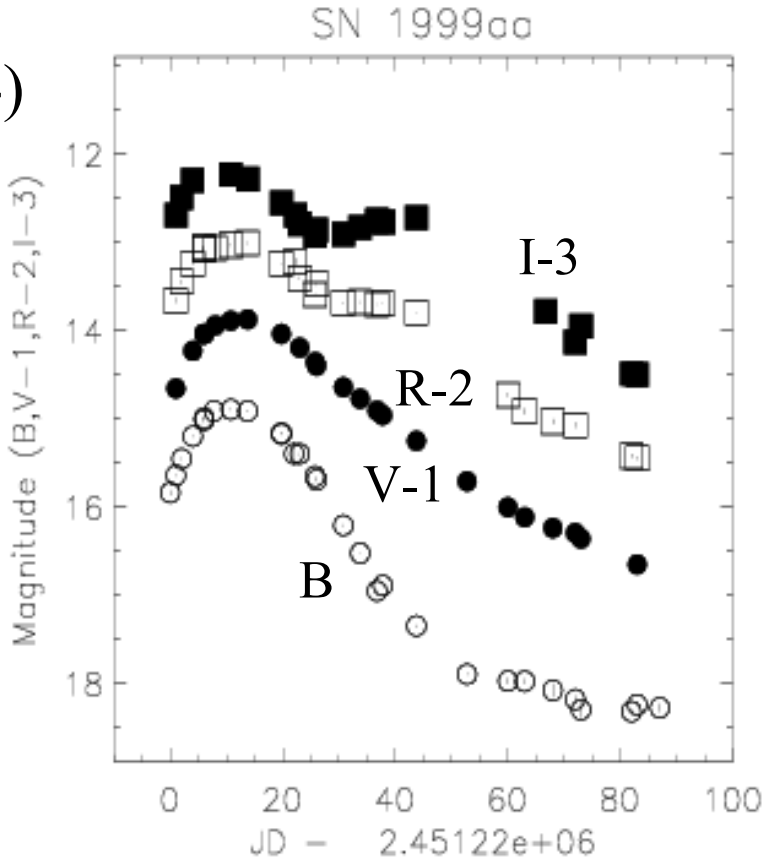
Synthetic spectrum (SYNOW) compared with SN 1999aa spectrum for day -11.

Lightcurves from Spring 99 SNe dataset

- 20 nearby SN observed (z =0.02-0.24)
- ~2600 images in UBVRI
- 17 different instruments

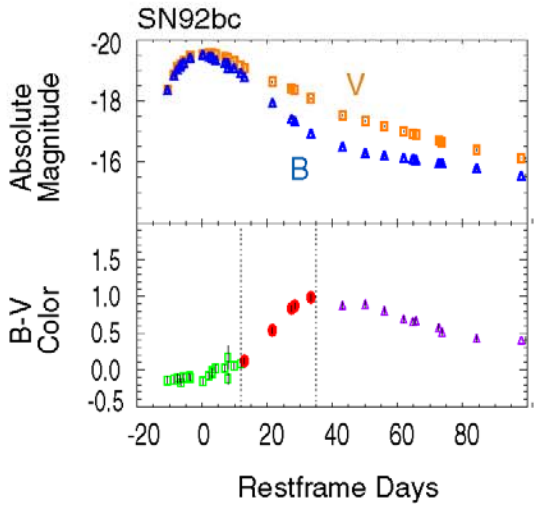
- The goal is to obtain well determined light curves of the SNe observed.

- Calibration precision of ~ 2% currently achieved.



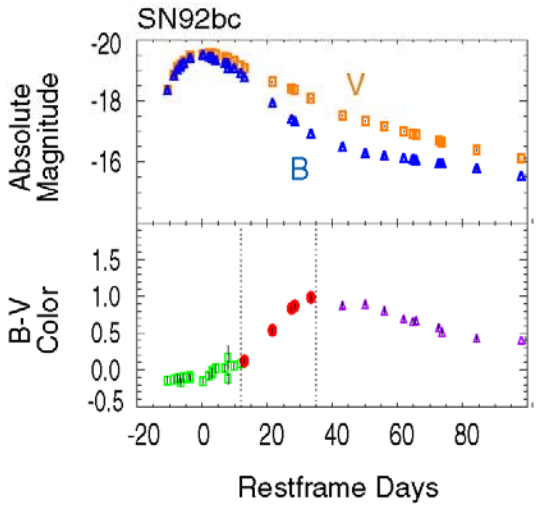
M. Kowalski, B. Farris

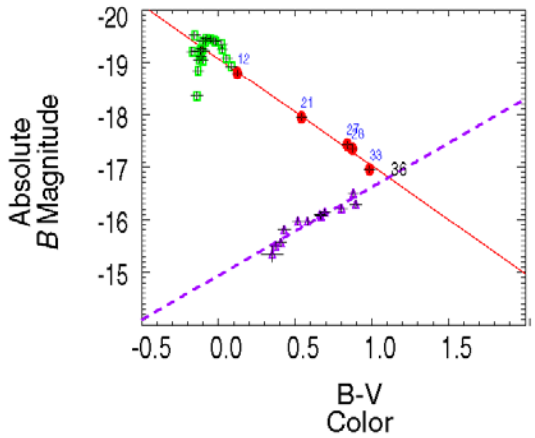
Color-Magnitude Intercept Calibration Technique for Type Ia Supernovae



Wang, Goldhaber, Aldering, & Perlmutter (2003)

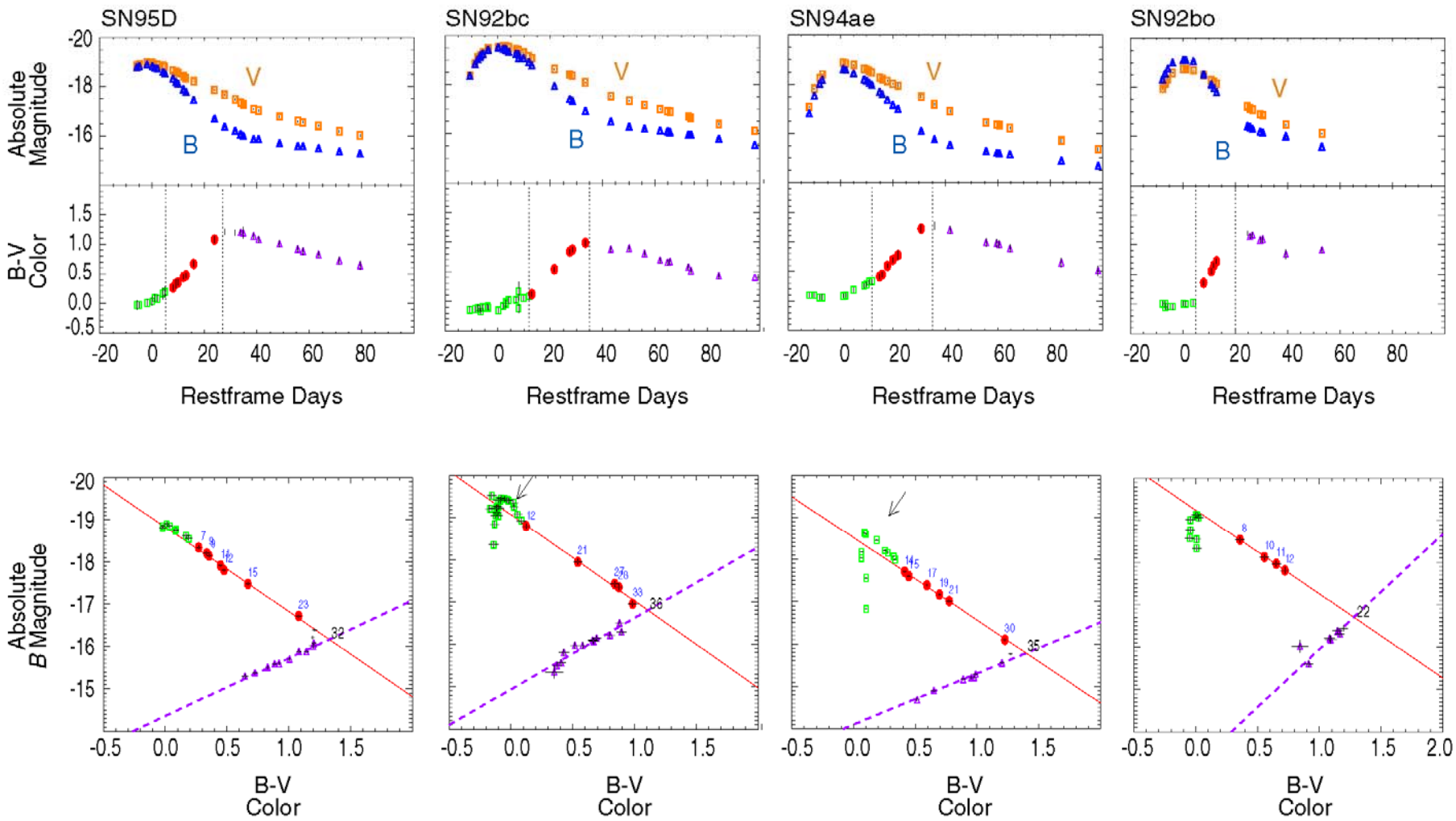
Color-Magnitude Intercept Calibration Technique for Type Ia Supernovae





Wang, Goldhaber, Aldering, & Perlmutter (2003)

Color-Magnitude Intercept
Calibration Technique for Type Ia Supernovae



Wang, Goldhaber, Aldering, & Perlmutter (2003)

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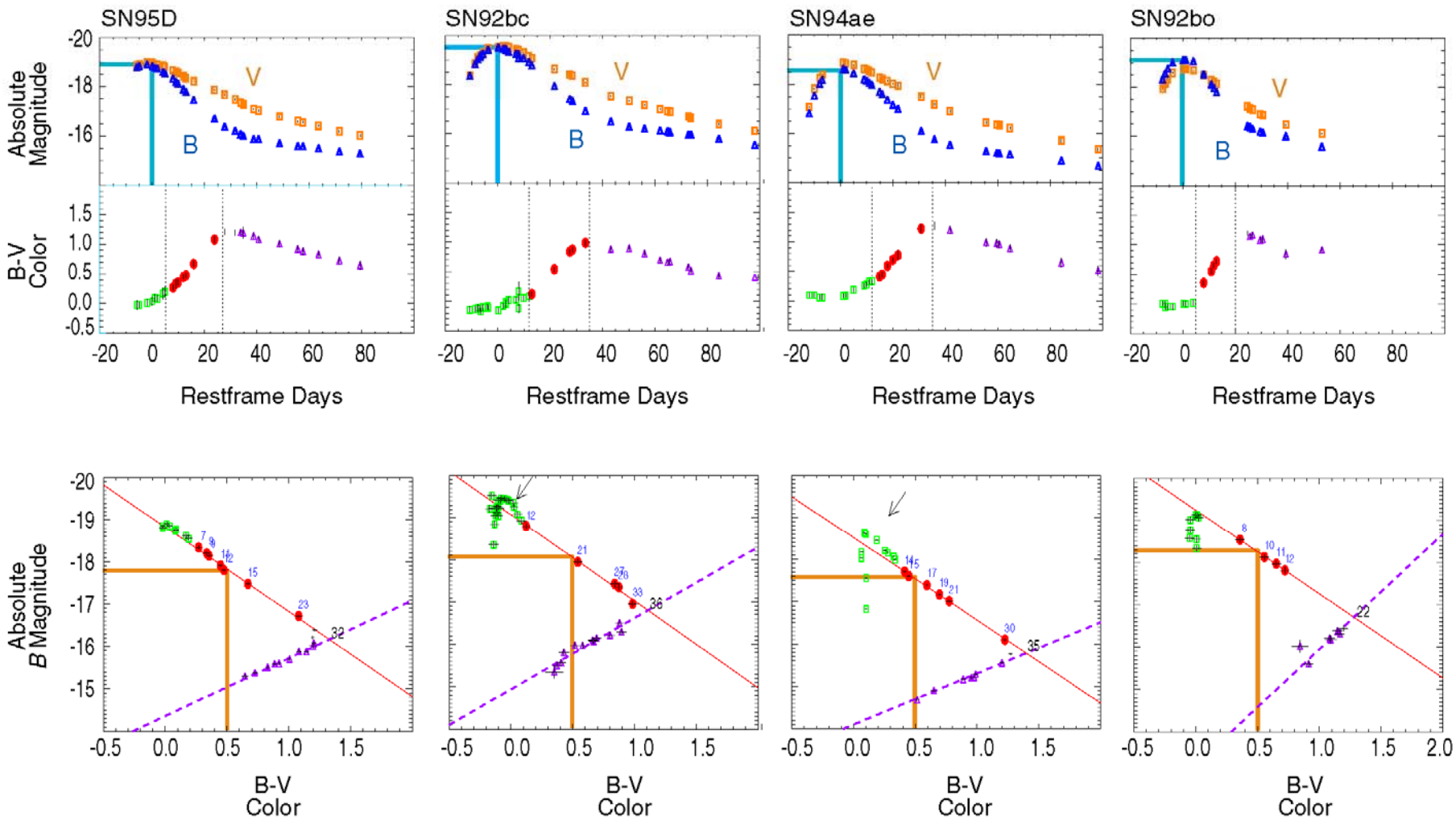
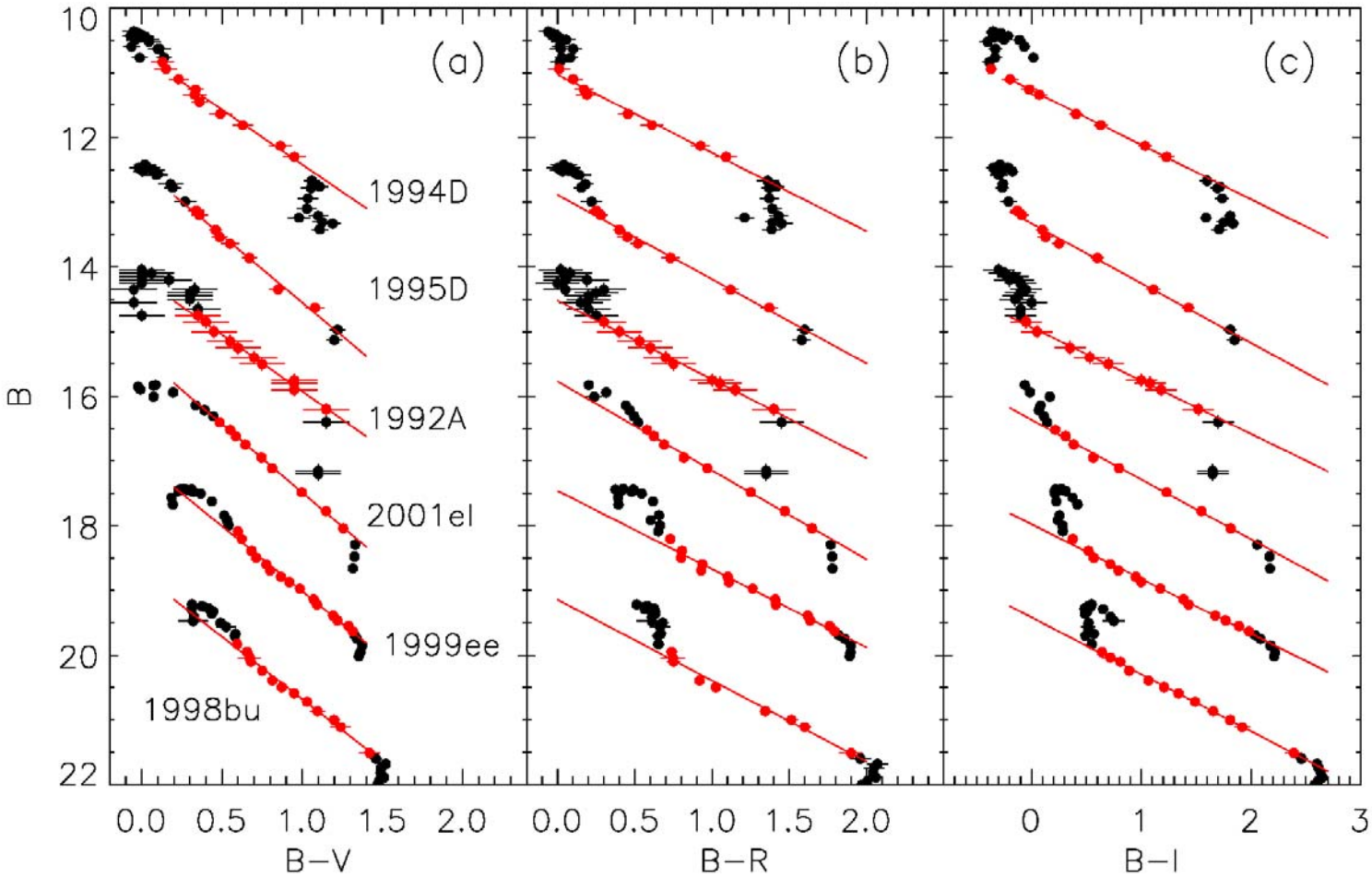


Wang, Goldhaber, Aldering, & Perlmutter (2003)

CMAGIC intrinsic dispersion & CMAGIC in other colors

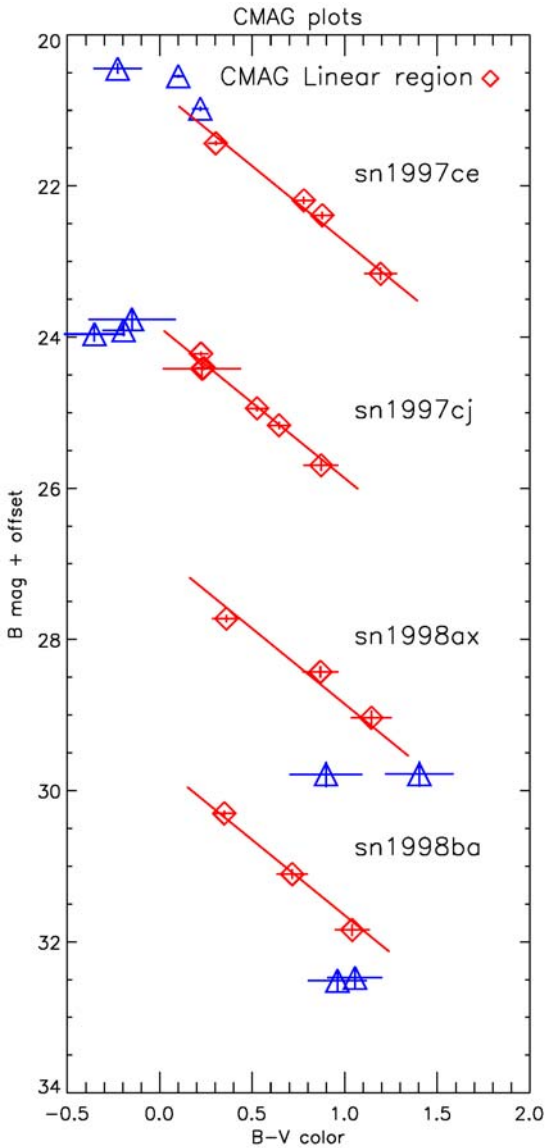


Wang, Strovink, Goldhaber, Siegrist, Perlmutter, Conley

Apply CMAGIC to high redshift SNe

- alternative method provides systematic cross check of previous results
- SCP + literature SNe
- cosmology fit done as "blind" analysis - conceal final results while developing analysis

A. Conley, PhD thesis in prep.



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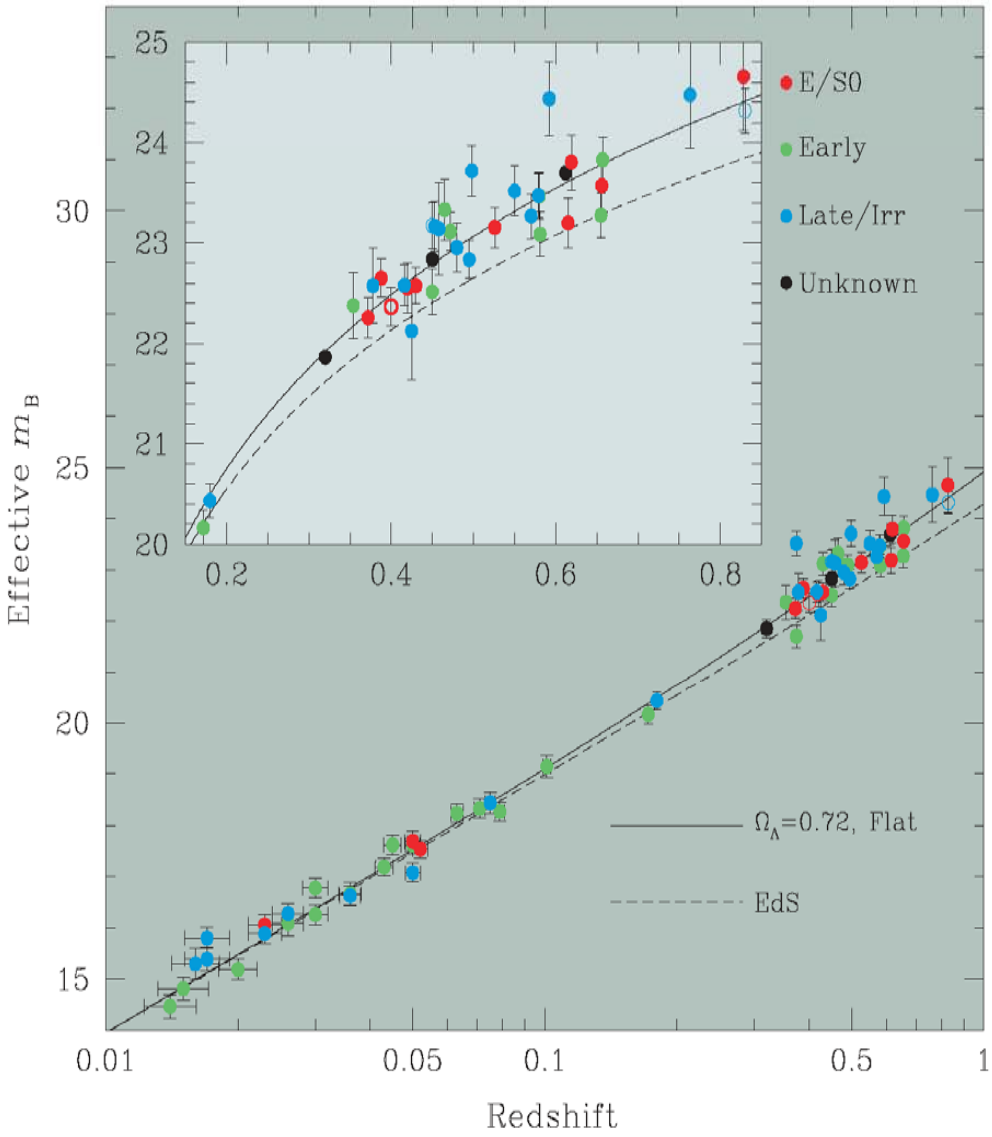
Sullivan, et al. (2003)

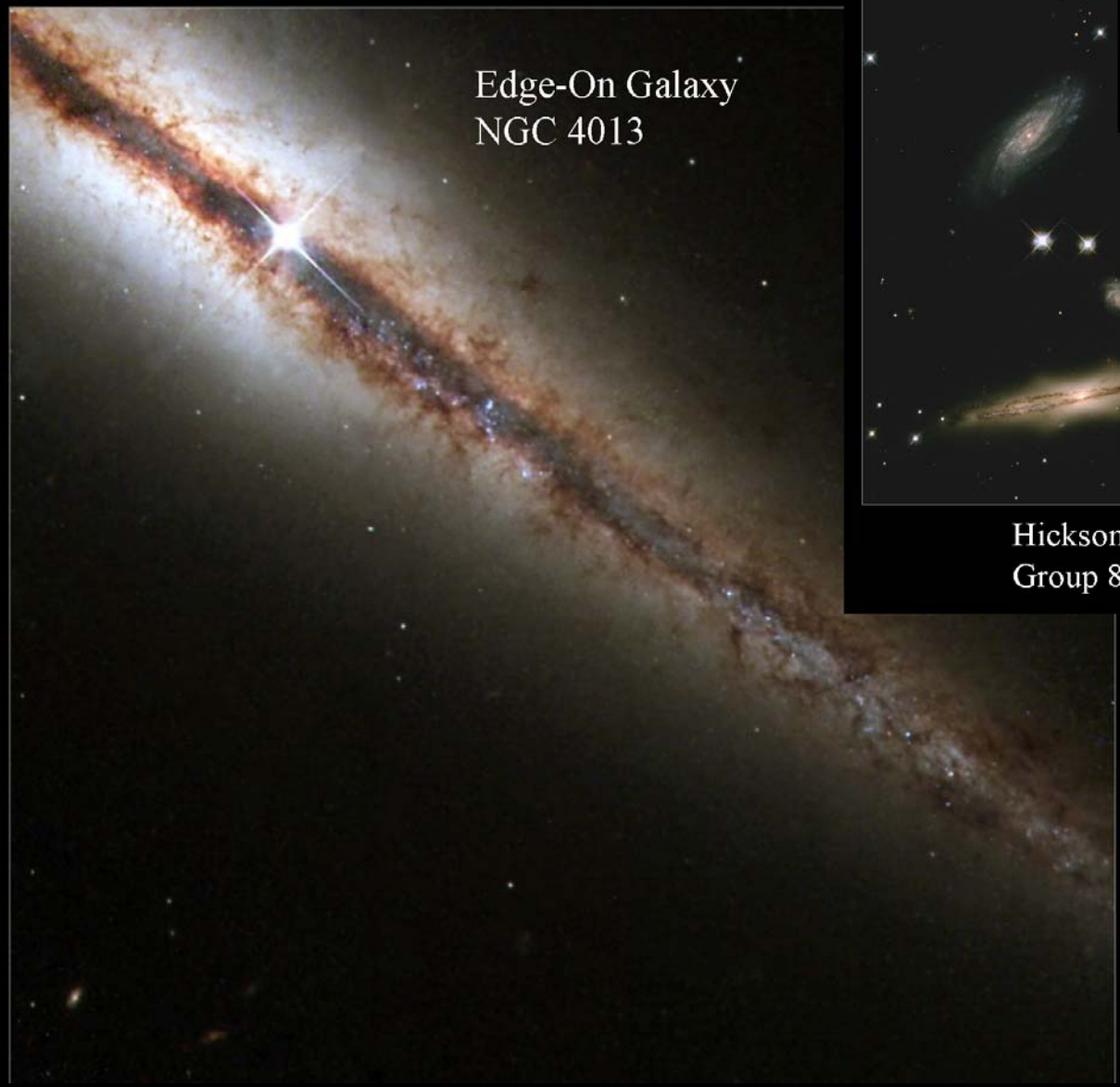
Supernova Cosmology Project

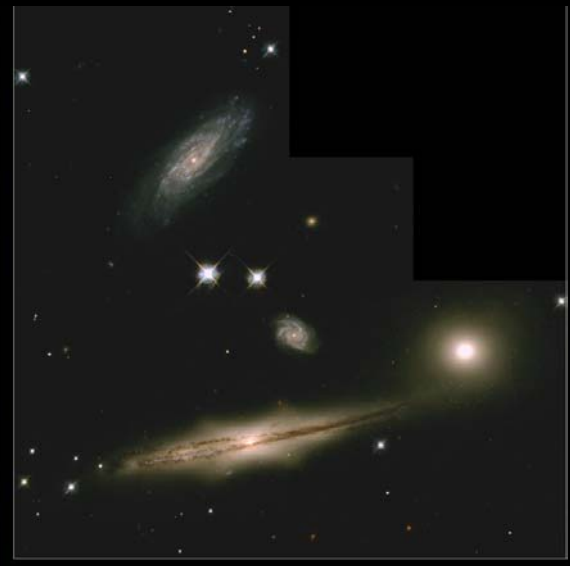


galaxy type	dispersion from best fit flat model
Elliptical: E/S0	$\sigma = 0.16$ mag
Spiral: Sa/Sb/Sc	$\sigma = 0.20$ mag
Late/Irregular: Scd/Irr	$\sigma = 0.27$ mag

Result from elliptical host galaxy subsample agrees with flat, $\Omega_\Lambda = 0.72$ result from whole dataset.

astro-ph/0211444





Hickson Compact
Group 87

SN

Dust

Lensing

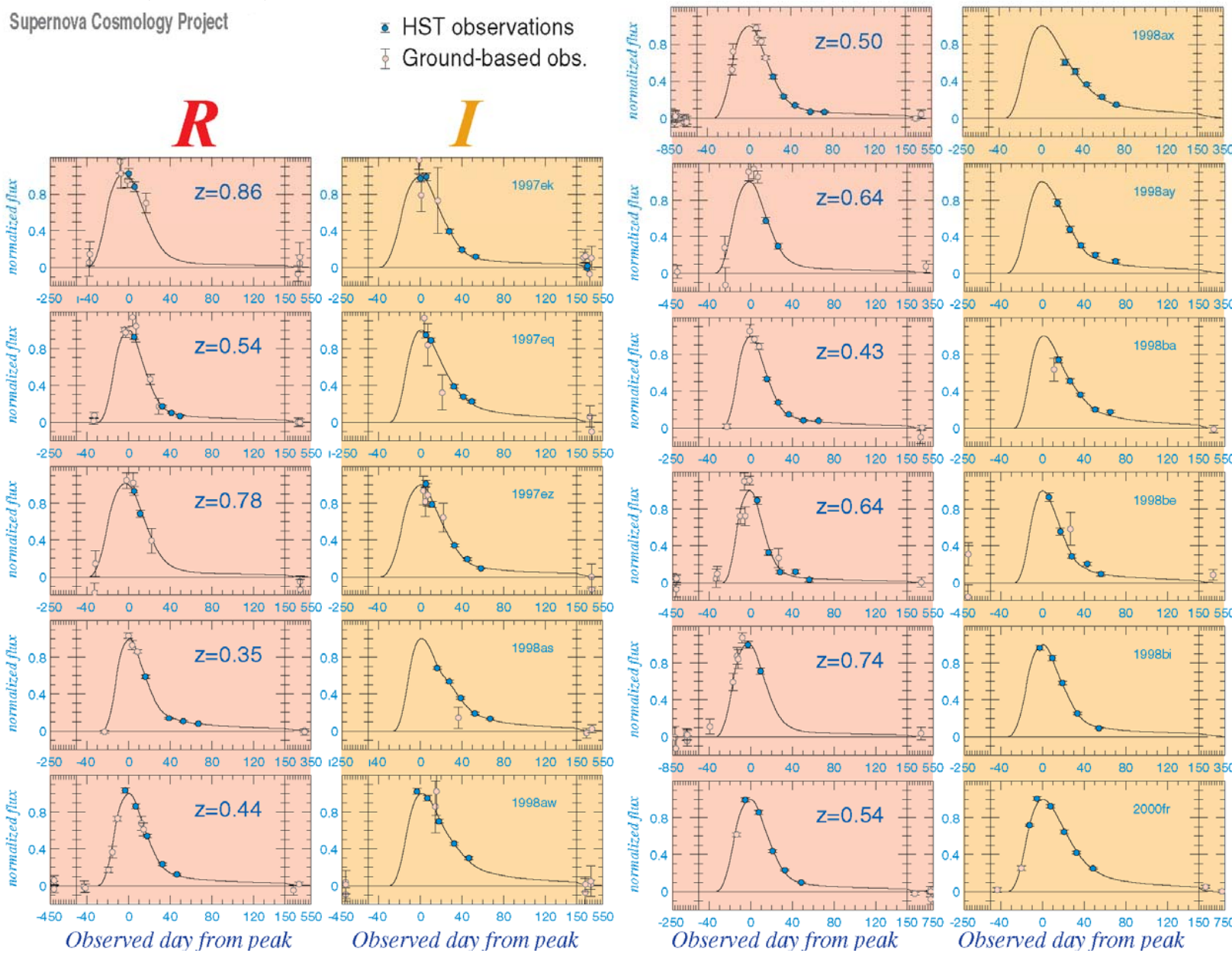
Optical IR Atmosphere

Filters

Optical IR Detectors

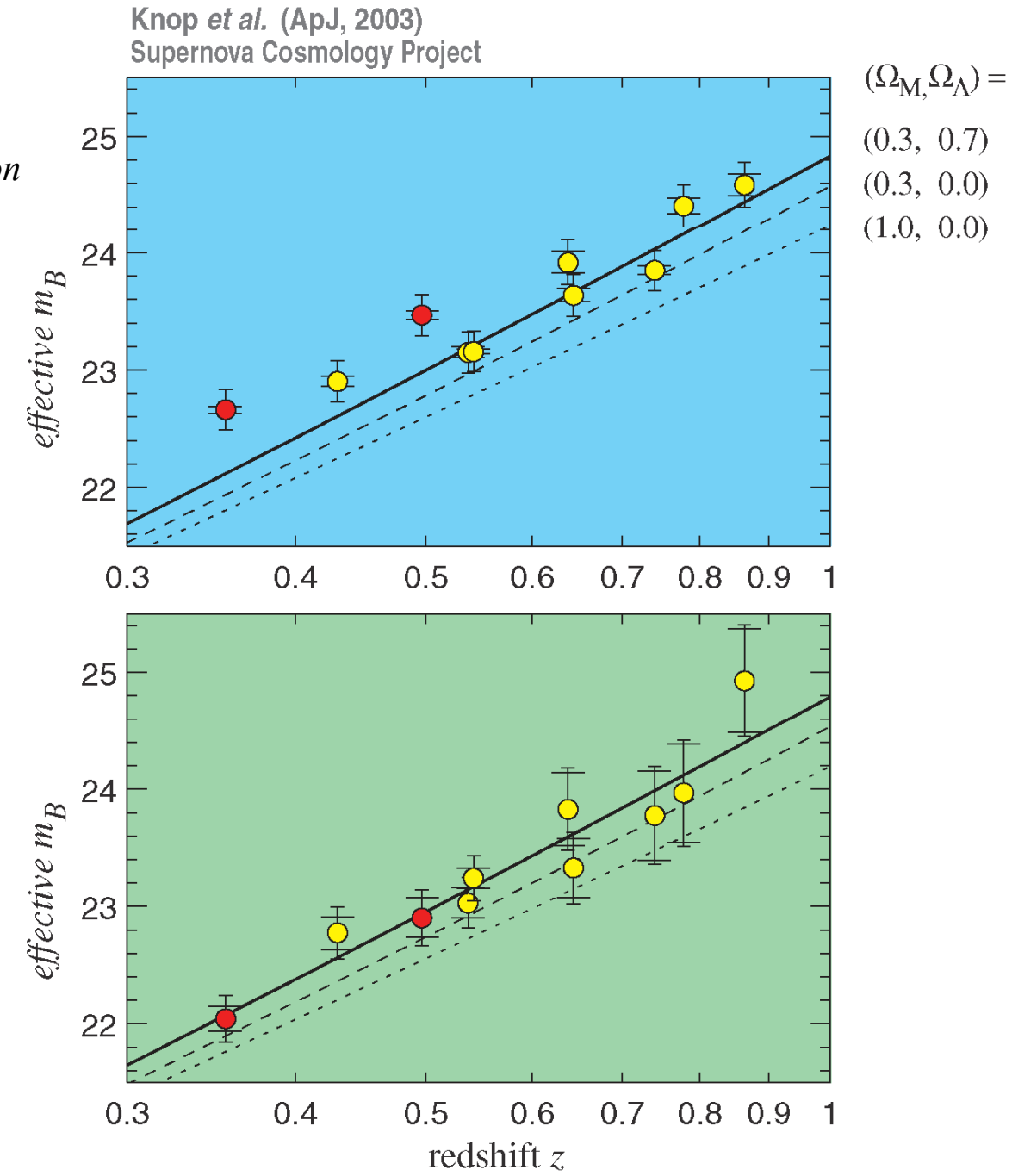
Interpretation

Knop et al (ApJ, 2003)



Before Extinction Correction

After Extinction Correction



Recent Publications

- Publications:
  - 1 published in AJ,
  - 1 accepted for publication A&A (astro-ph 0410506)
  - 3 close to submission, 4 drafts that have gone through several iterations
  - Many conference presentations/posters
- 5 SCP PhD theses in 2003/4
  - 1 LBL - M. Wood-Vasey (SNfactory) (+ A. Conley Spring '05)
  - 3 Stockholm University
  - 1 Paris (LPNHE)

Recent publications (2)

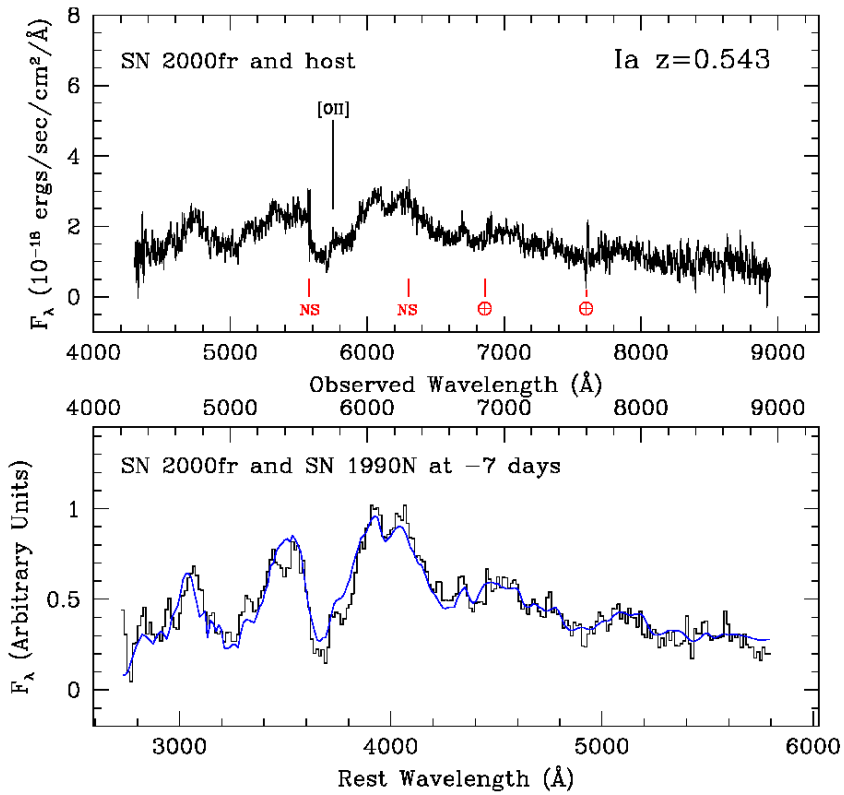
Spectroscopic confirmation of high-redshift supernovae with the ESO VLT

C. Lidman et al., accepted for publication in Astronomy and Astrophysics. astro-ph # (Oct 20, 2004)

- spectra of 39 candidate high-redshift supernovae
  - •20 candidates are spectrally classified as SNe Ia $z = 0.212 < z < 1.181$.
  - •11 exhibit broad supernova-like spectral features and/or have supernova-like light curves.
  - •1 might be a type II SN

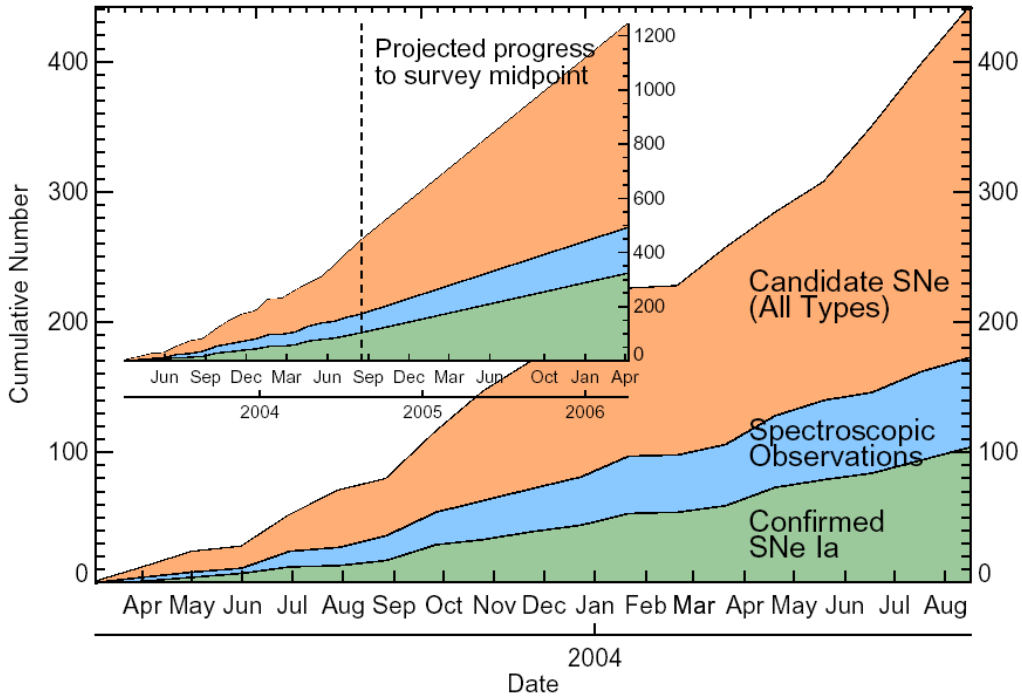
•over 80% of the observed candidates were spectrally classified as SNe Ia in searches targetting z ~ 0.5

• 4 candidates with $z > 1$ were spectrally classified as SNe Ia and later followed with ground & HST in searches targetting very high z.

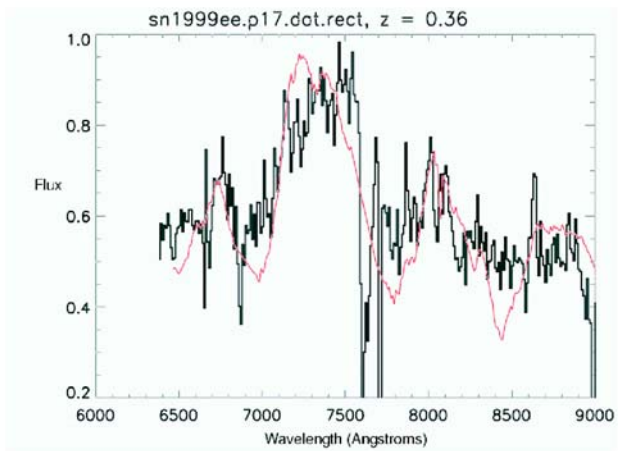


SuperNova Legacy Survey at CFHT

- Started March '03. 40 (d) nights/year for 5 years
- 4 square degrees : u', g', r', i', z'
- g',r',i',z' every 2-3 nights for 10 months/yr
- 15', 30', 1h, 30'
- Detection up to z = 1.2 -1.3
- Multicolor LC follow- up up to z=0.9
- 2000 SN Ia + 2000 SN II ? + AGNs ? + ..
- 600 well measured SNIa 0.3<z<0.9

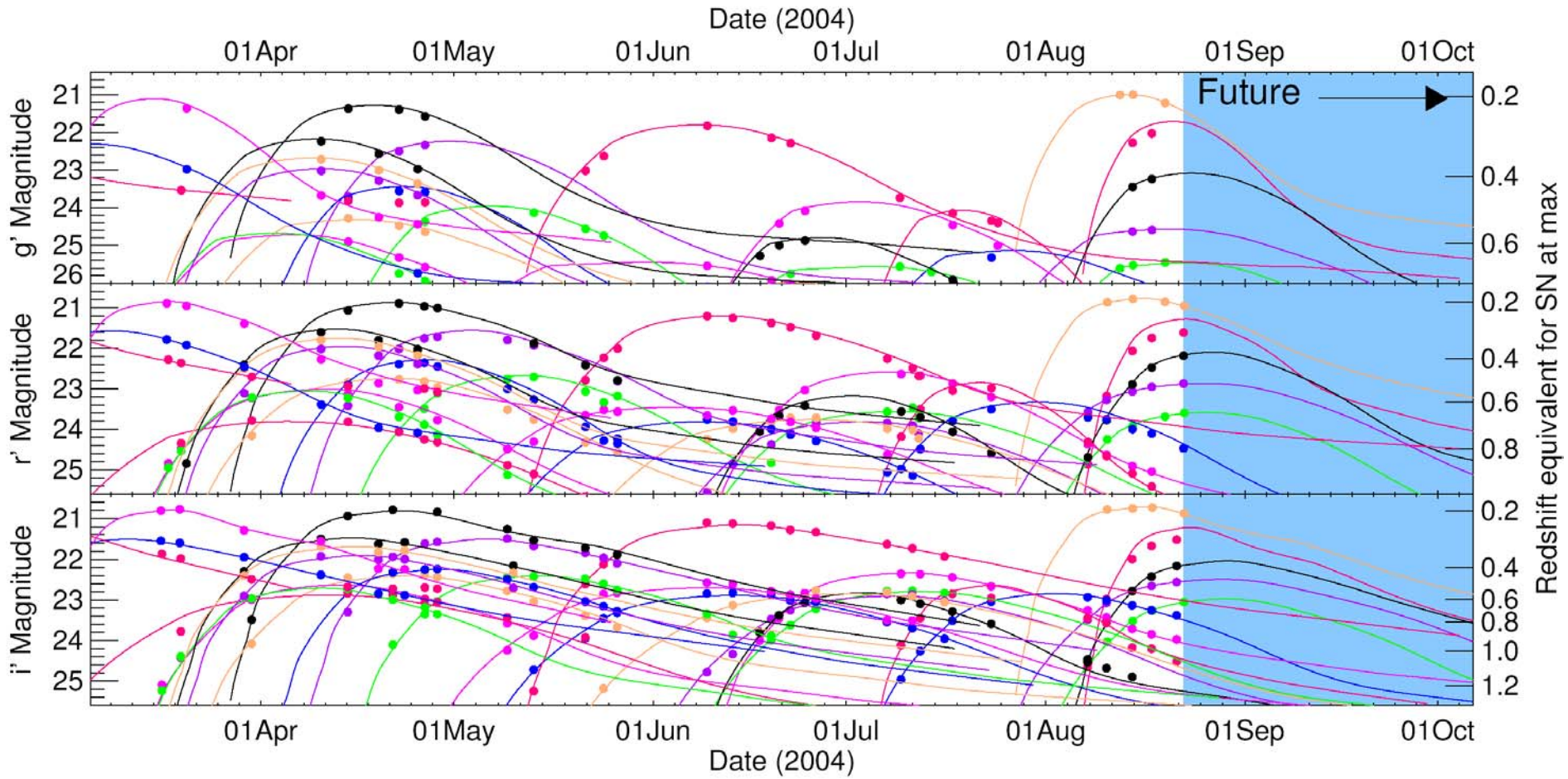


- LBL group: spectroscopy for SN type and redshift
  - Keck (DEIMOS, LSI)
  - Gemini (GMOS)



S. Perlmutter,
G.Aldering,
A. Conley,
J. Newman,
+collaborators

SuperNova Legacy Survey at CFHT



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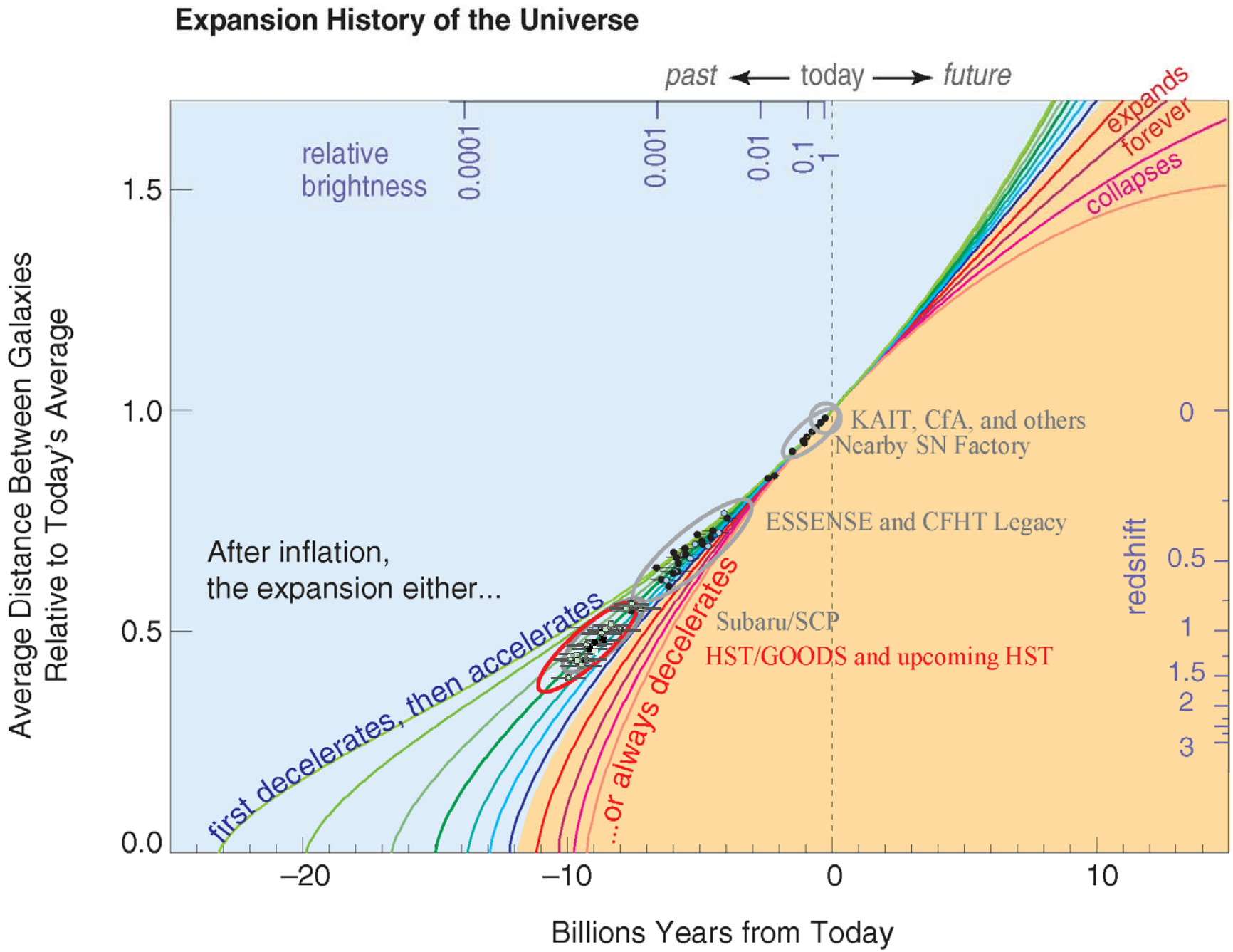
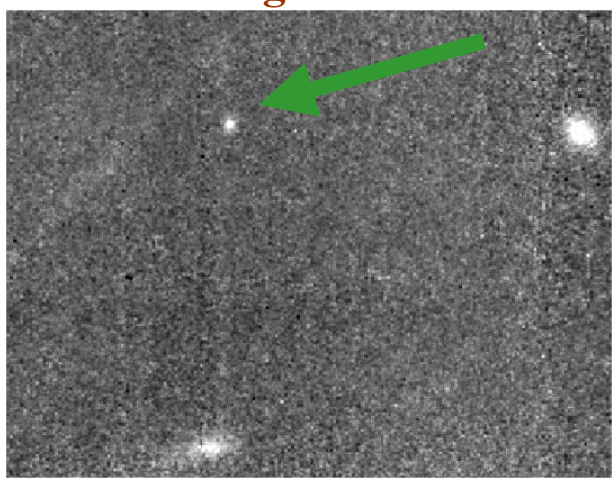

Expansion History of the Universe
past
today
future
relative brightness
0.0001
0.001
0.01
0.1
1
expands forever
collapses
KAIT, CfA, and others
Nearby SN Factory
ESSENSE and CFHT Legacy
Subaru/SCP
HST/GOODS and upcoming HST
redshift
0
0.5
1
1.5
2
3
After inflation,
the expansion either...
first decelerates, then accelerates
...or always decelerates
Average Distance Between Galaxies
Relative to Today's Average
1.5
1.0
0.5
0.0
–20
–10
0
10
Billions Years from Today

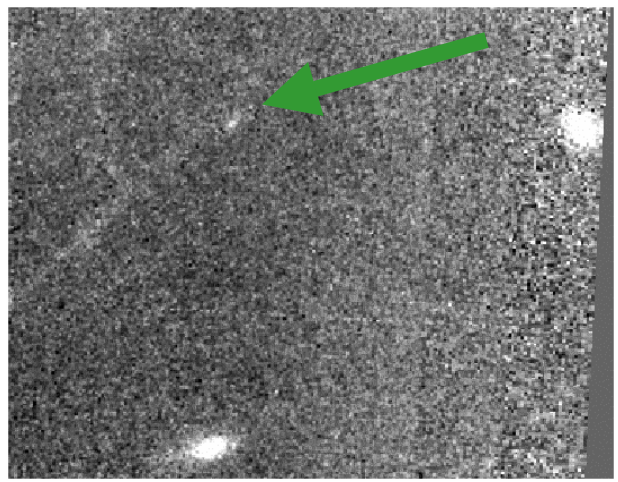
SN 1998eq (Albinoni) at redshift 1.2

- Discovered with the Keck 10-m and followed with HST.
- First discovered supernova which exploded during the epoch of deceleration.
- Deeply imbedded in the light of its host galaxy
- Premature coolant depletion on the HST infrared NICMOS instrument delayed taking of needed final references until 2002.

NICMOS signal data

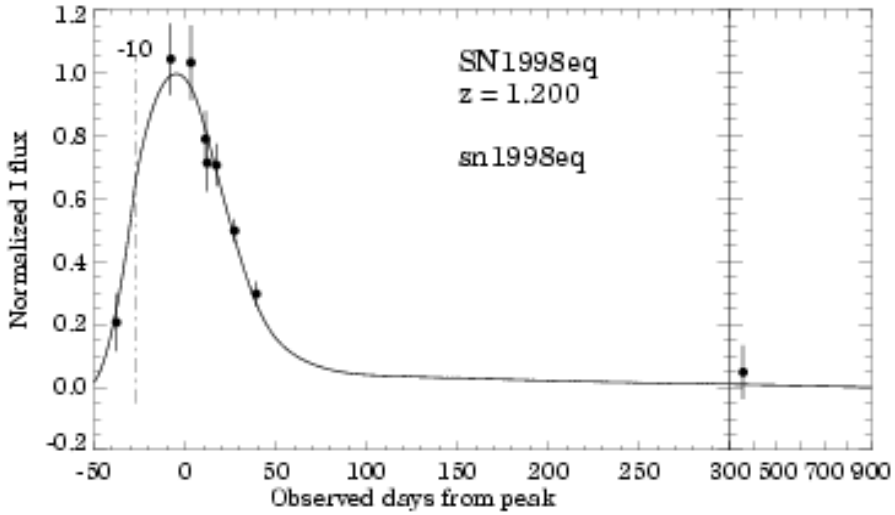


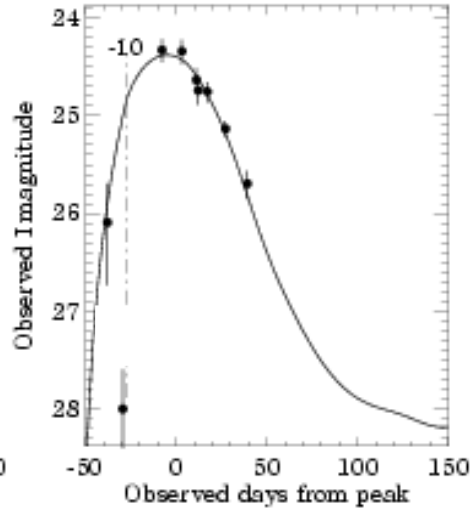
NICMOS final ref



V. Fadeyev
G. Aldering

Albinoni lightcurve: ground and space data





V. Fadeyev

G. Aldering

SN color measurement from the observed I and J bands indicates low extinction $E_{B-V} = 0.00 \pm 0.08$ ***(preliminary)***.

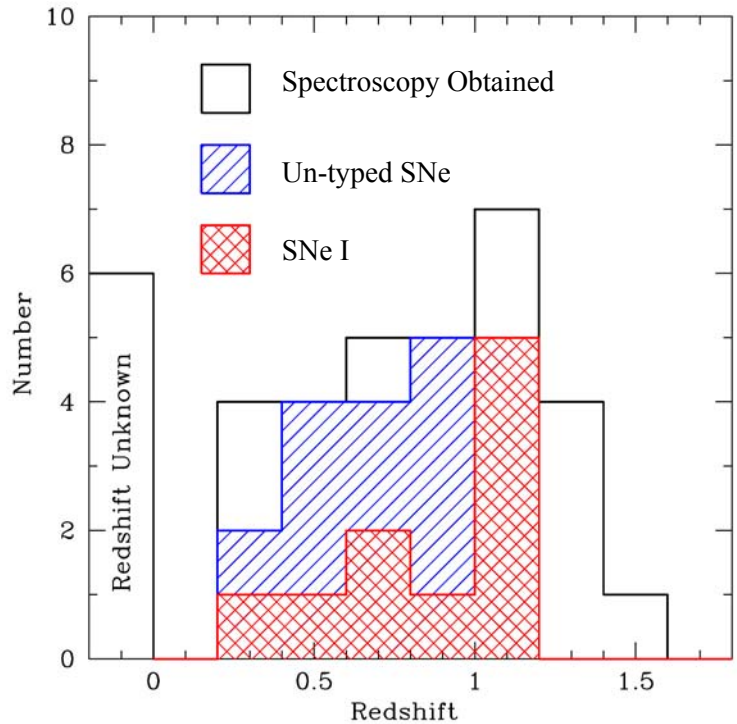
Work is in progress to estimate the extinction from the available spectrum and the host galaxy colors.

SCP SN studies using Subaru

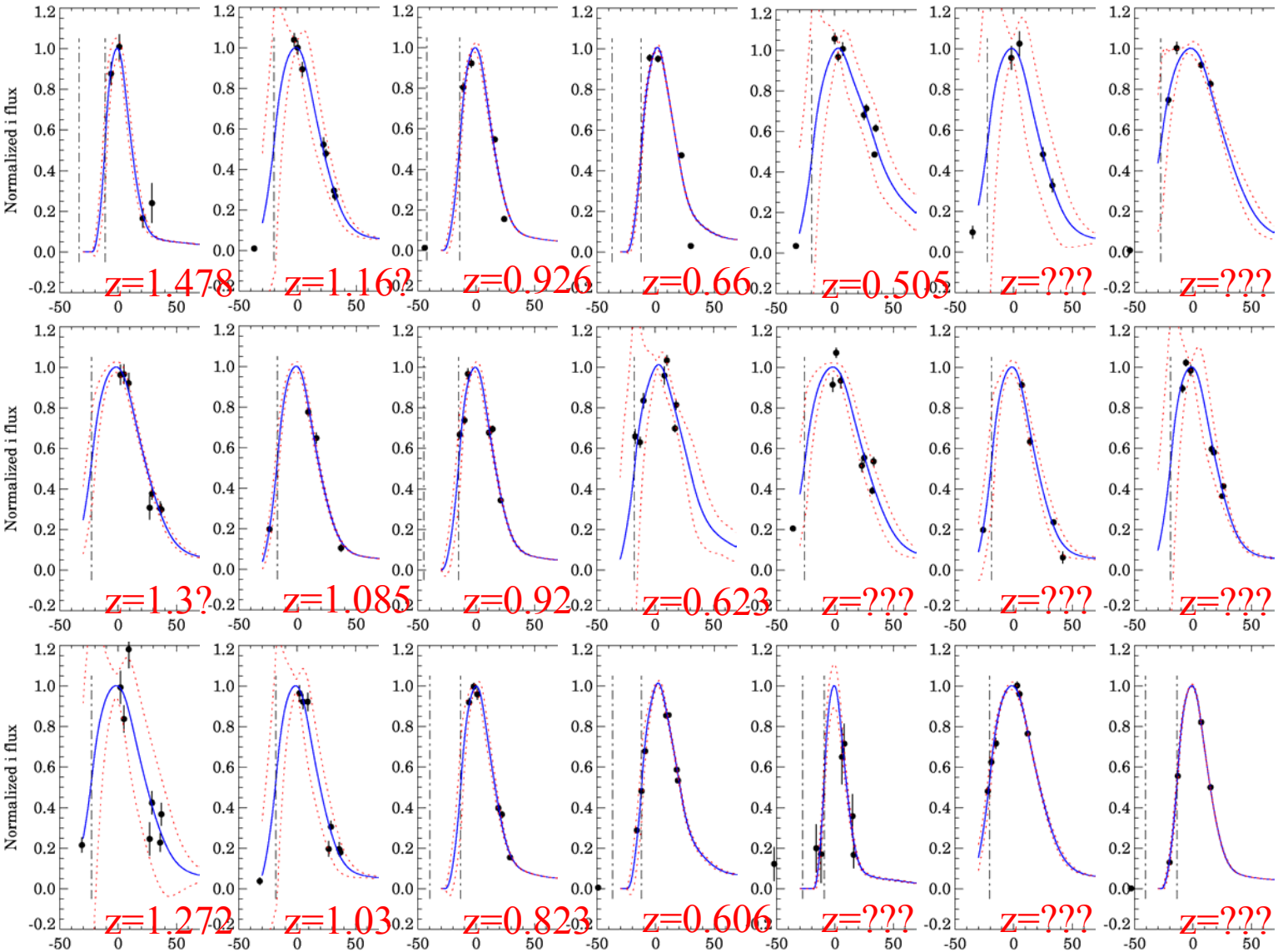
- A series of high redshift SN search with Subaru/ Suprime-Cam
- Widest field imaging camera on 8-10m class telescopes and has a FOV of 33 x 26 arcmin.

	Candi-dates	Spectrum	SNe	Spec. Confirmed SNe Ia	HST
Spring 01	22	8	7	3	1
Spring 02	55	13	7	5	4
Fall 02	44	22	25	5	3
Total	121	48	39	13	8

G. Goldaber, K. Dawson, V. Fadeyev, Tokyo group

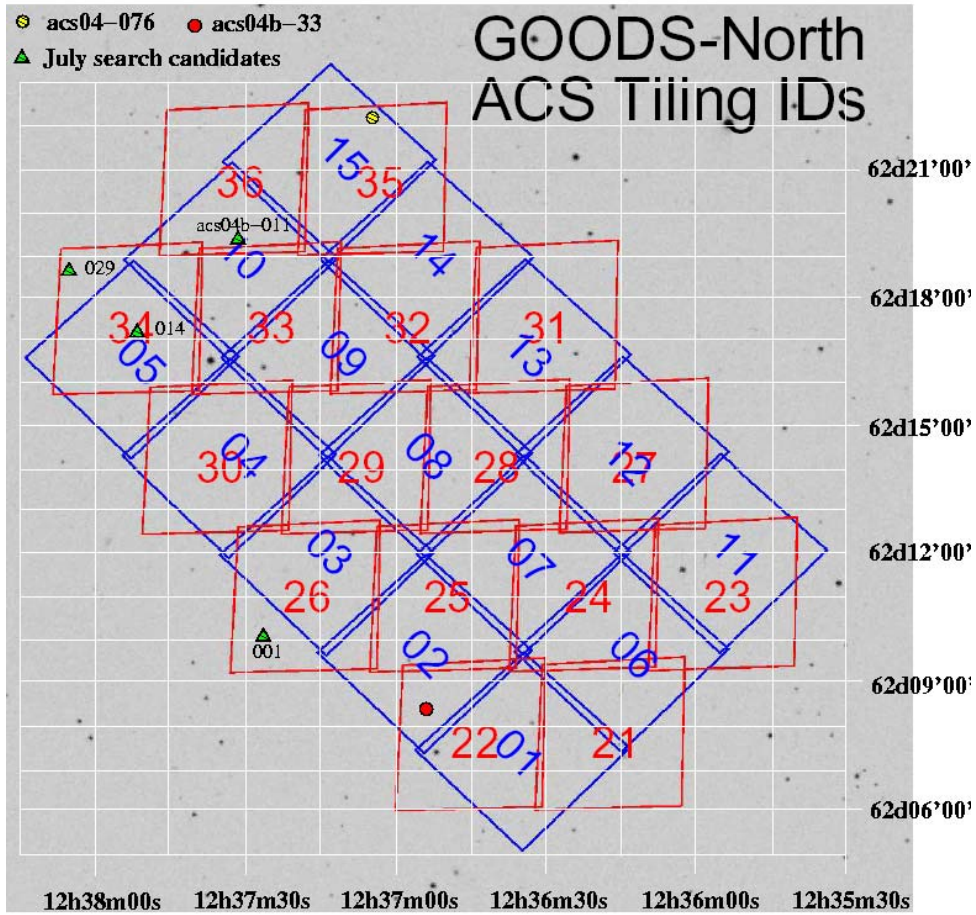


Preliminary lightcurves (ground-based data)

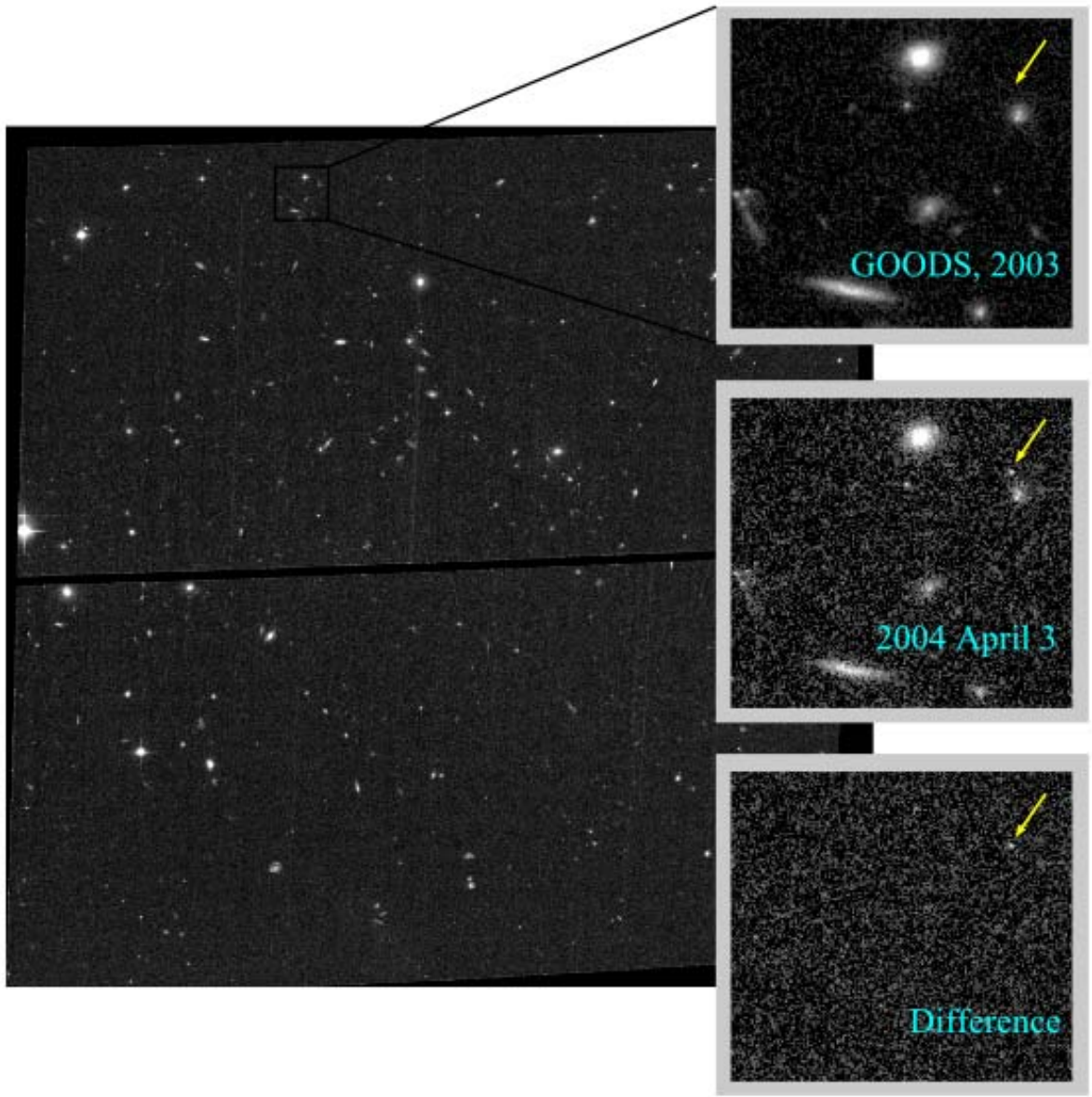


2004 Search for SNe z > 1.2 with HST

- Use the Advanced Camera for Surveys (ACS) to image GOOD-N area of sky (170 sq arcmin).
- 4 search epochs (April - Aug) separated by ~7 weeks.
- Search done in collaboration with STScI group
- Find 1-2 high z candidates/search epoch
- 60 orbits used for follow-up for multi-color light curve studies
- April search
  - SN Ia? at z ~ 1.7 (photo-z and ACS grism spectrum)
- July search
  - SN at hjigh-redshfit (1.3- 1.5 from photo-z). Type not confirmed. ACS grism spectrum being analyzed.

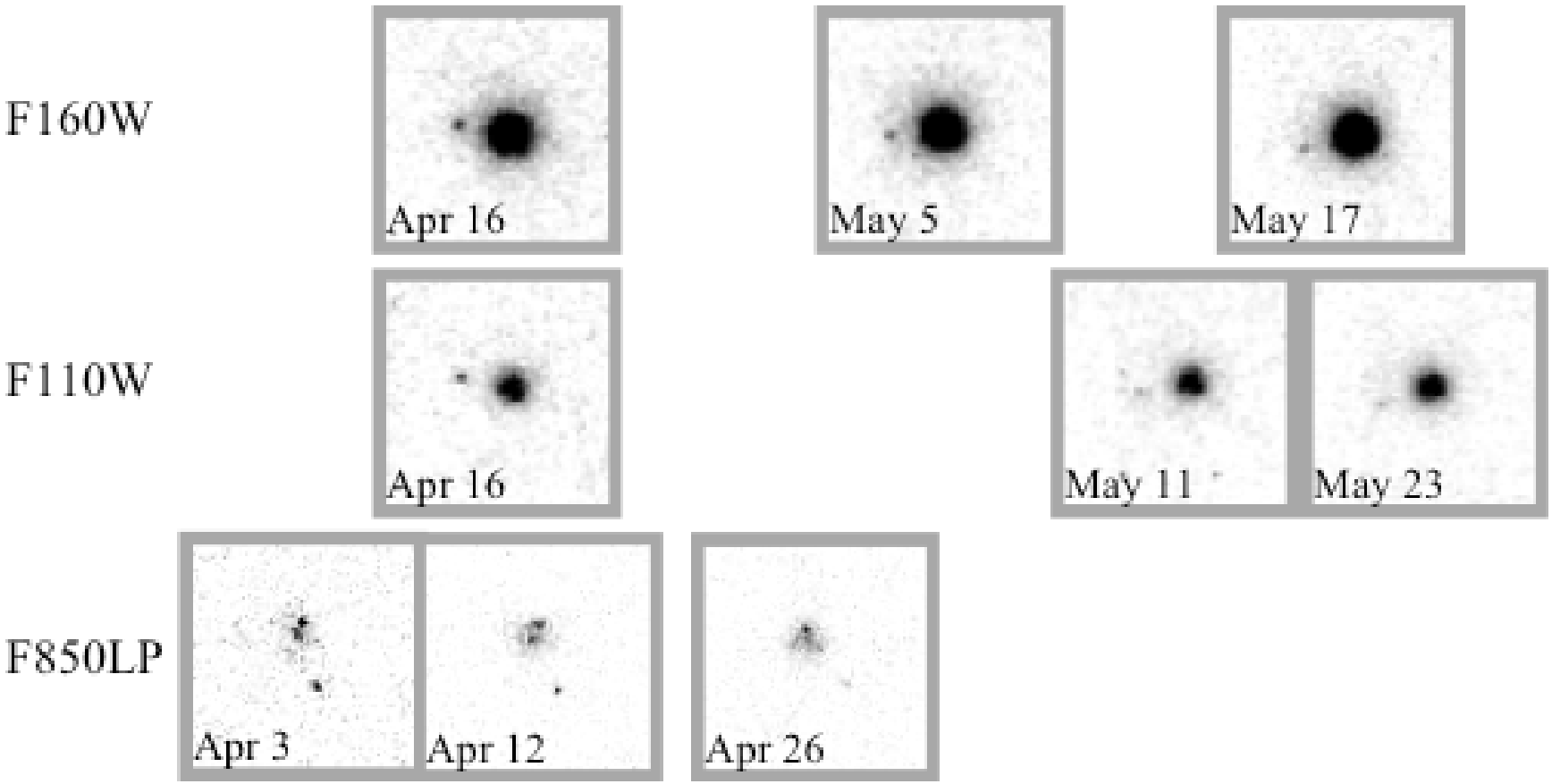


April SN candidate z ~ 1.7



R. Knop, R. Gibbons,
N. Kuznetsova

April SN lightcurve followup



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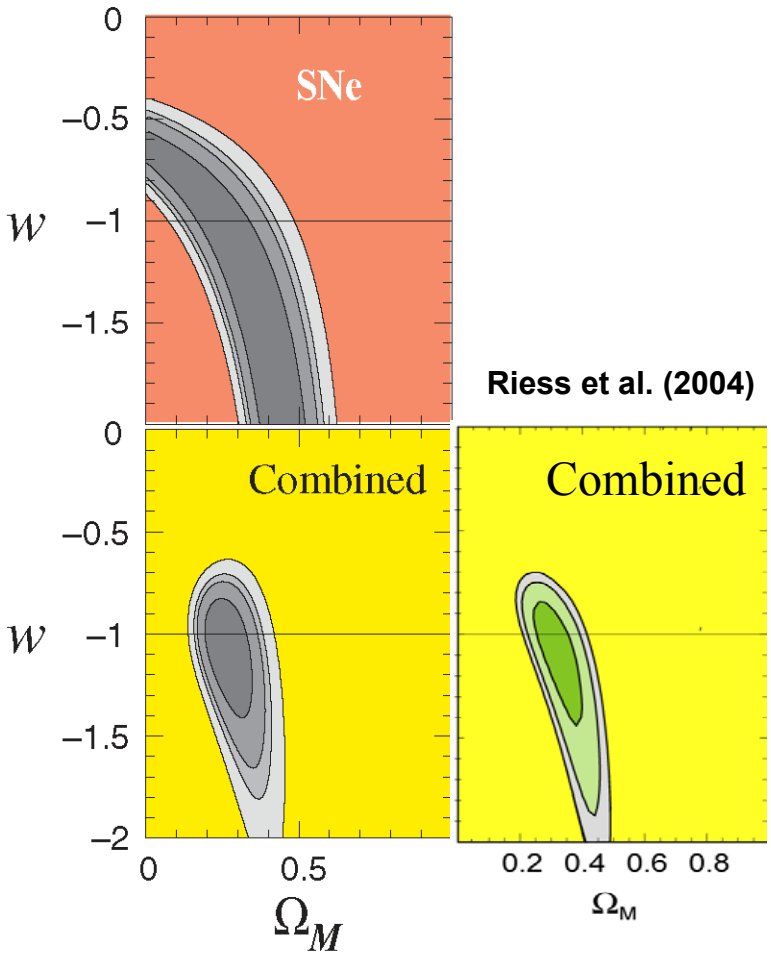
SNAP co-PI's: Perlmutter & Levi

Supernova Cosmology Project
Knop *et al.* (2003)

Assuming constant-w prior

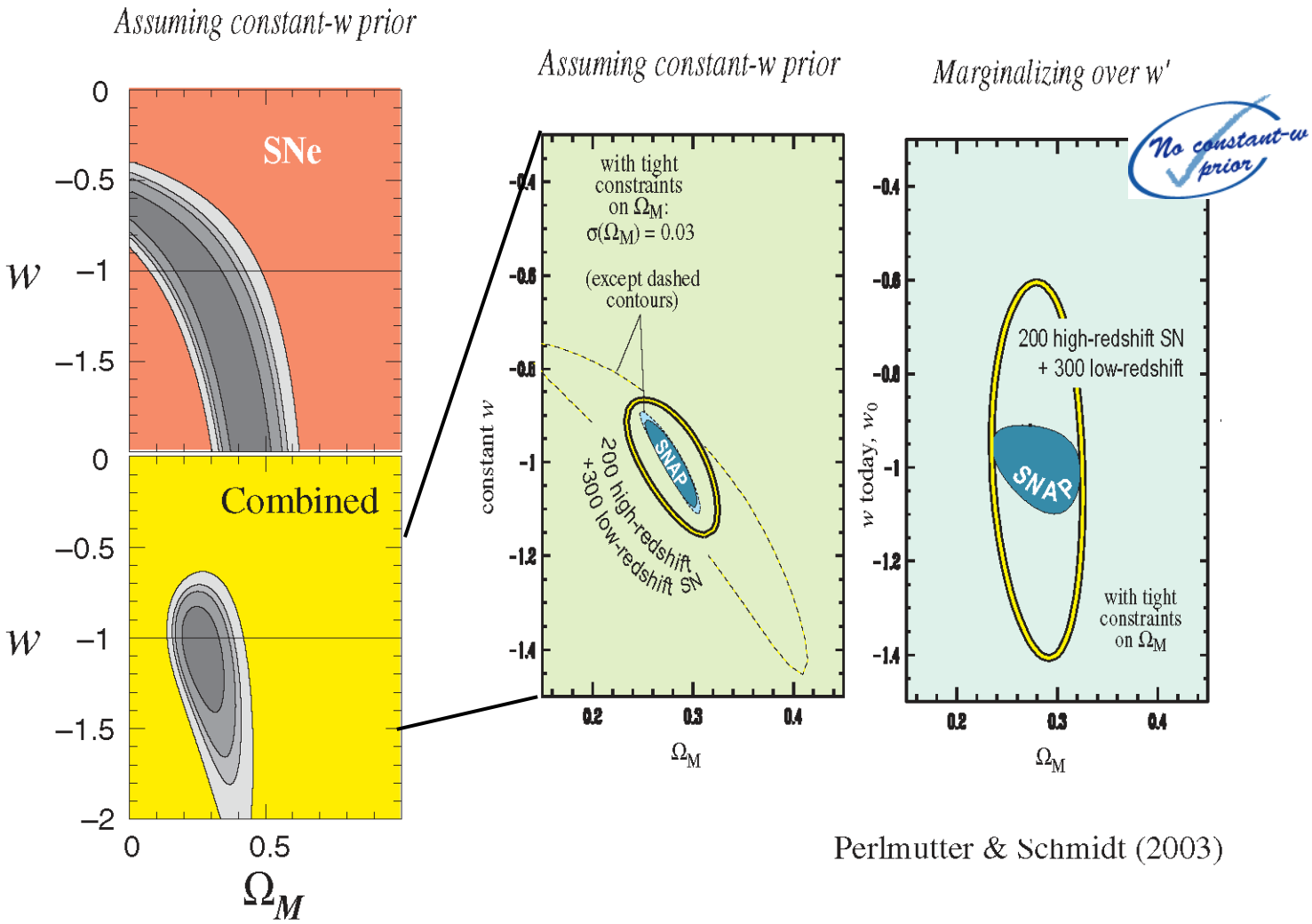


Riess et al. (2004)

With limits from;
2dFGRS (Hawkins et al. 2002)
and CMB (Bennet et al. 2003,
Spergel et al. 2003)

Supernova Cosmology Project
Knop *et al.* (2003)

Expected future measurements of w



Perlmutter & Schmidt (2003)

With limits from;
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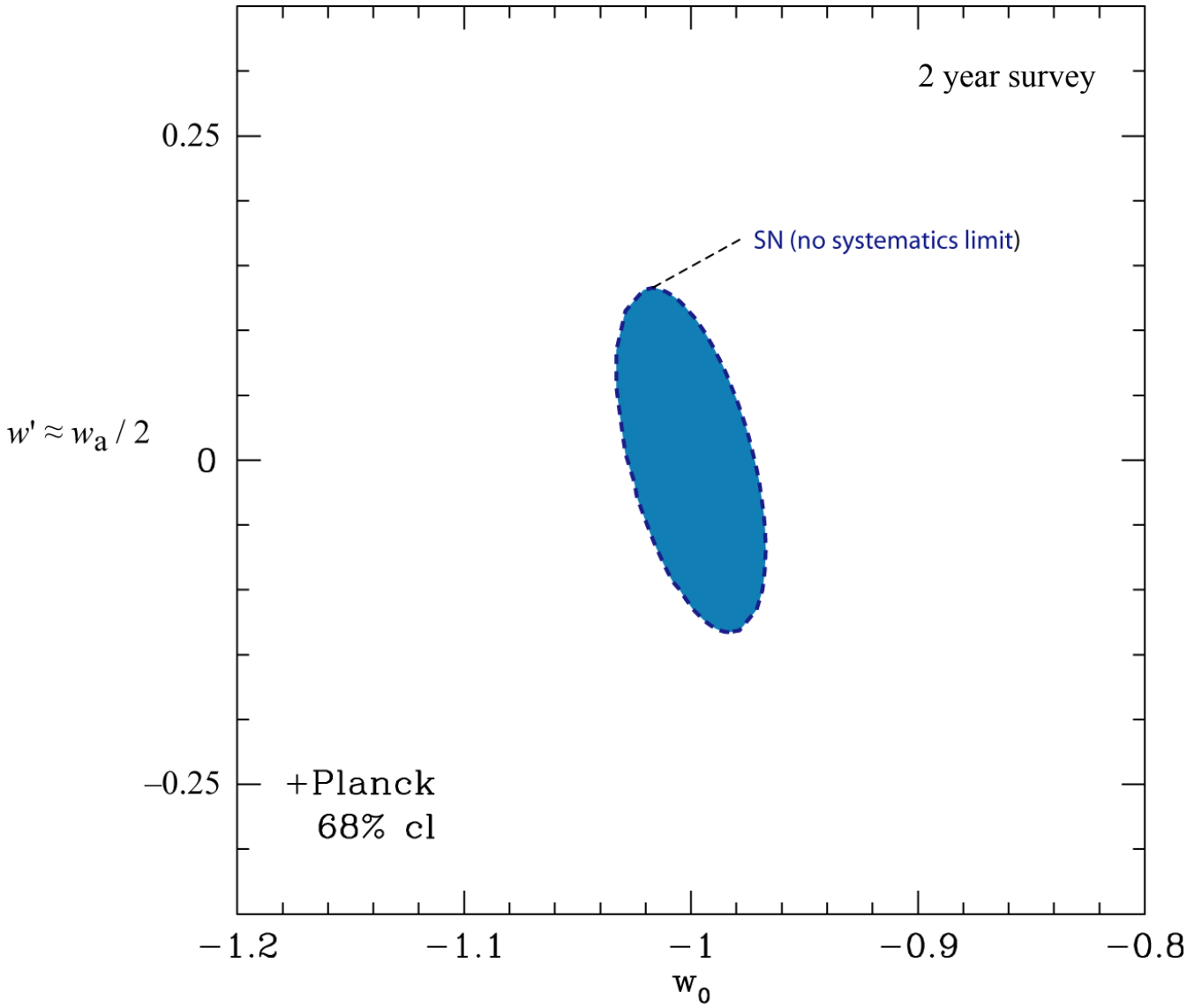
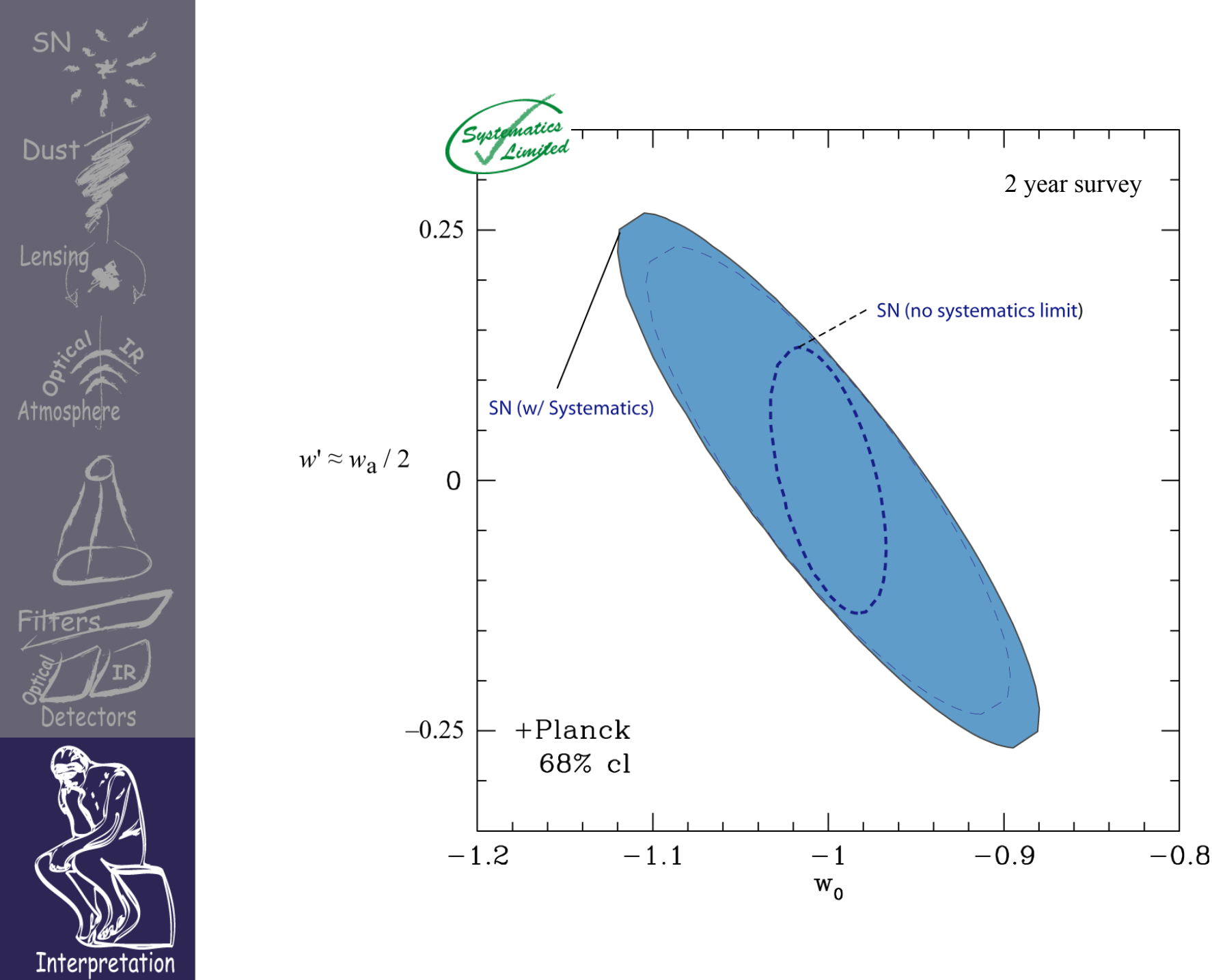
SN
Dust
Lensing
Optical
IR
Atmosphere
Filters
Optical
IR
Detectors


Interpretation


2 year survey
SN (no systematics limit)
+Planck
68% cl
0.25
0
−0.25
$w' \approx w_a / 2$
−1.2
−1.1
−1
−0.9
−0.8
w_0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Systematics Limited
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0.25
0
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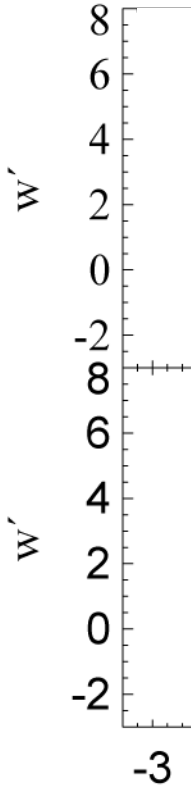
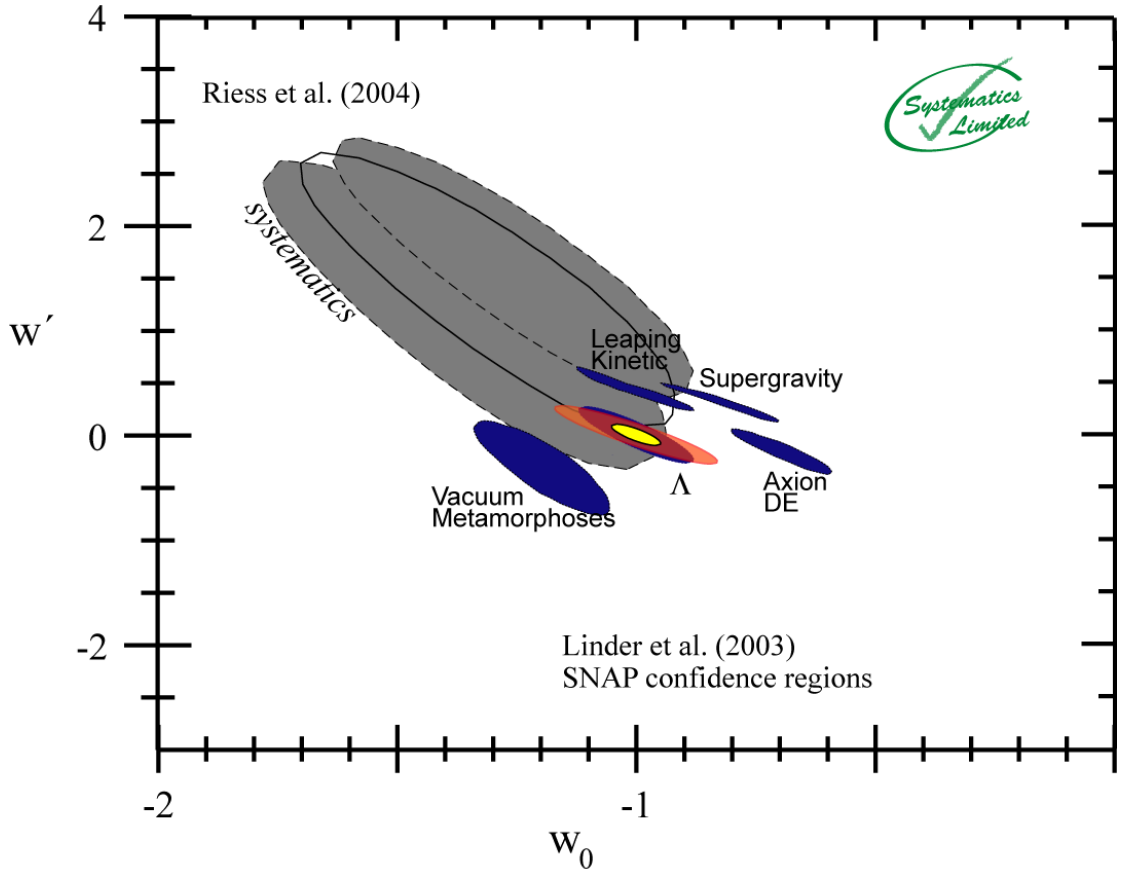
Riess et al. (2004)





SN

Dust

Lensing

Optical IR

Atmosphere

Filters

Optical IR

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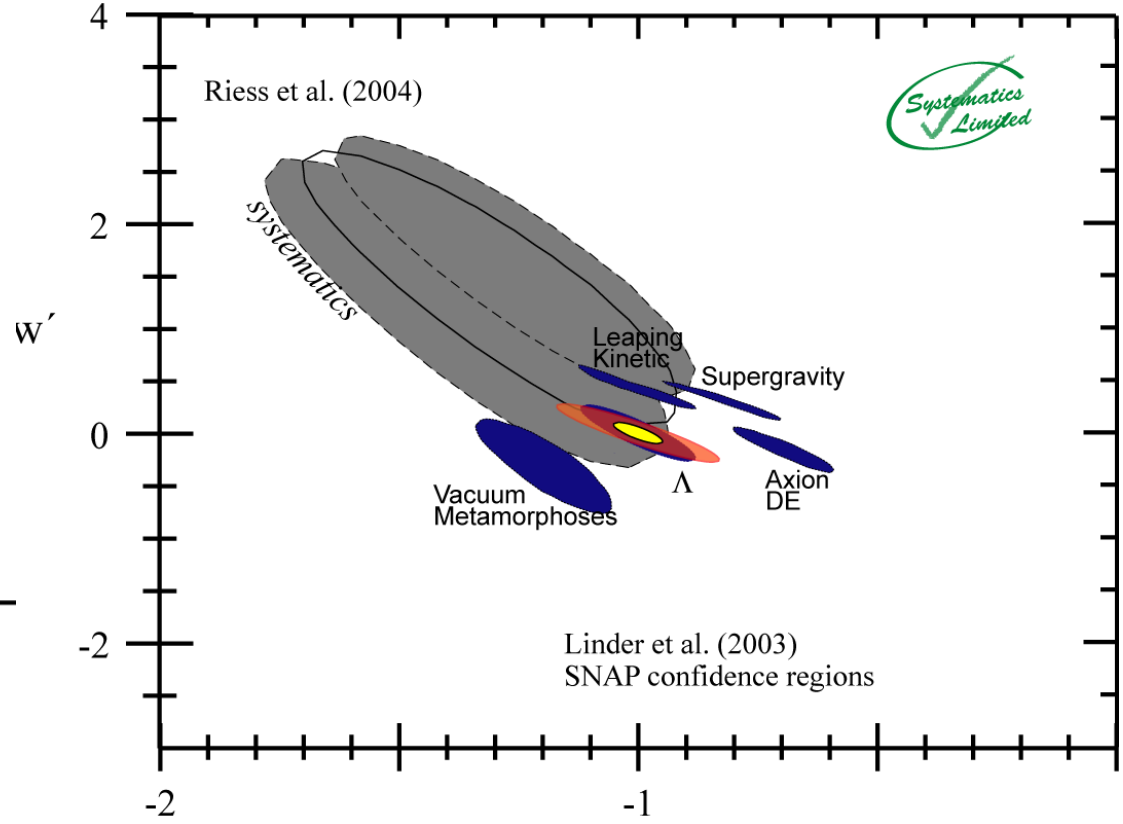

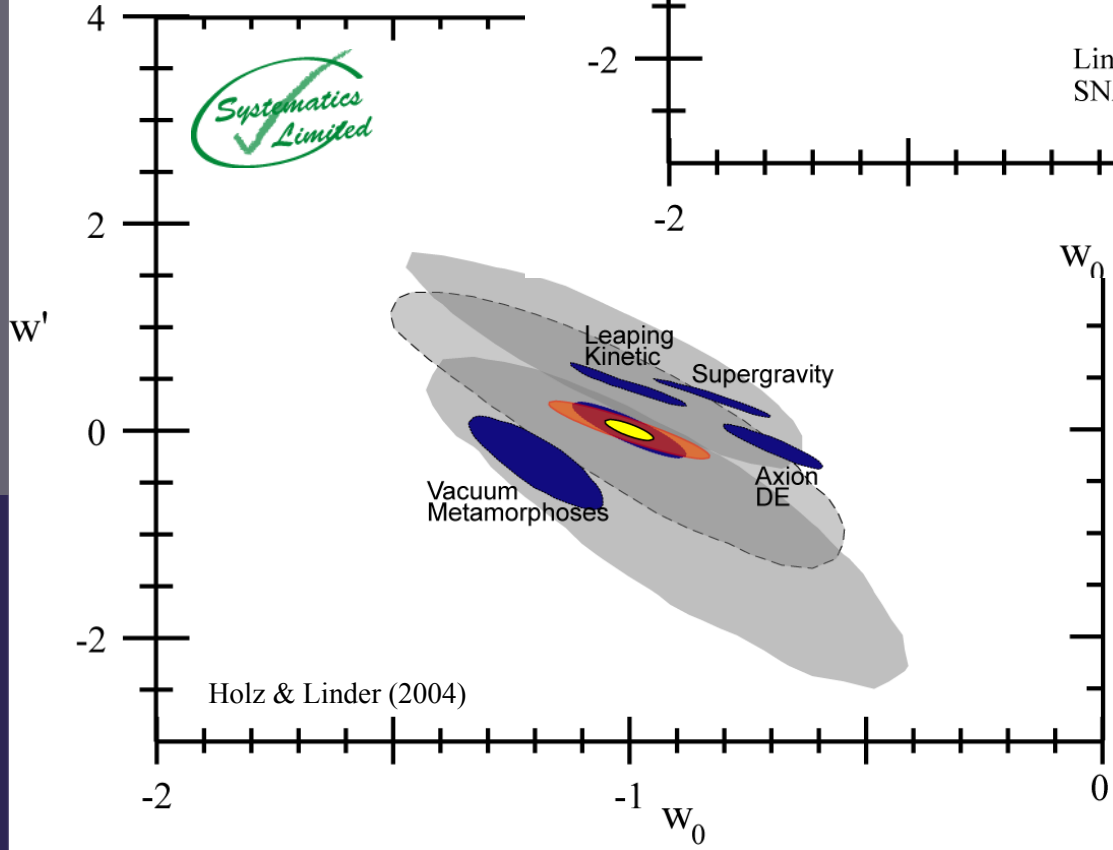

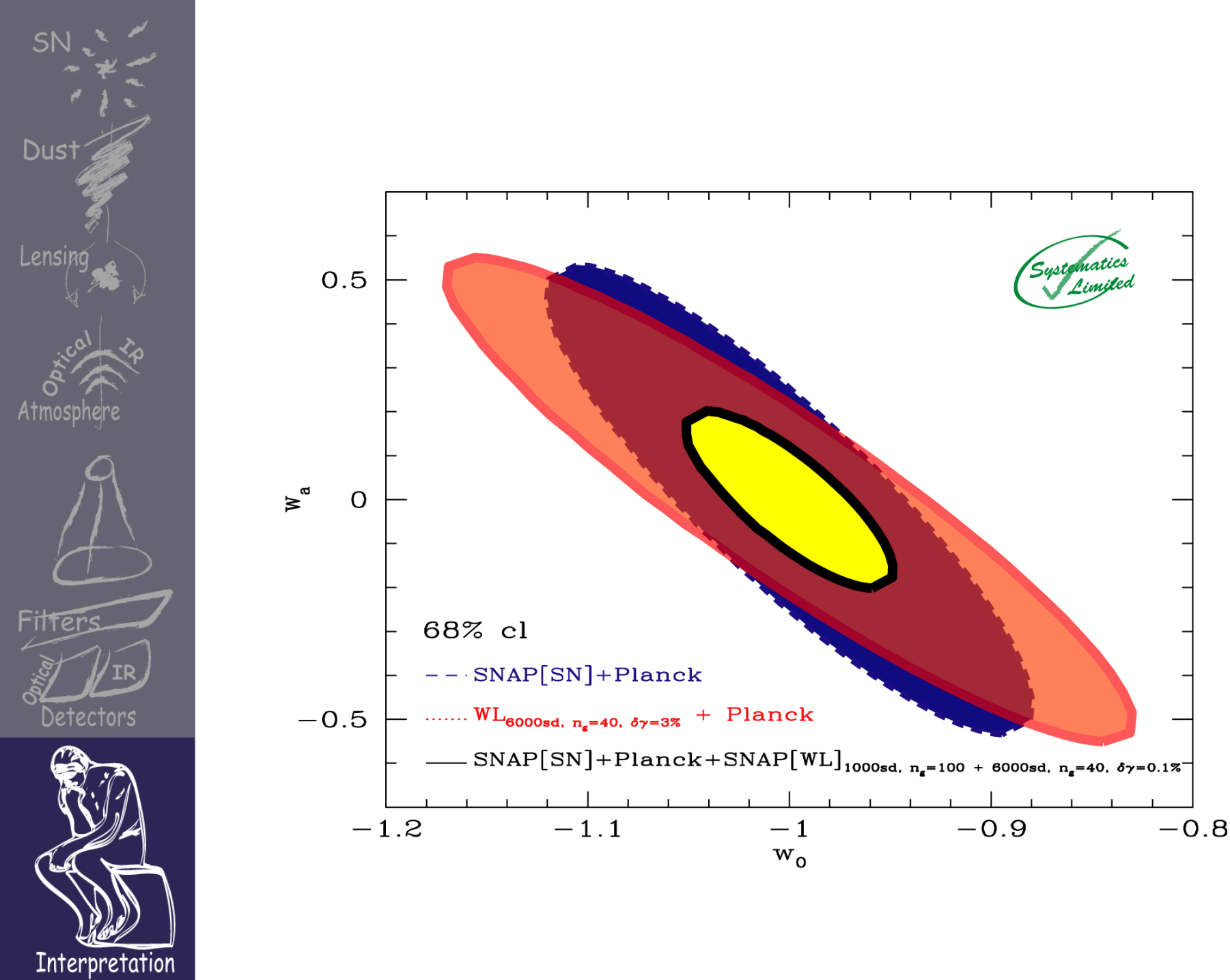
SN
Dust
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IR
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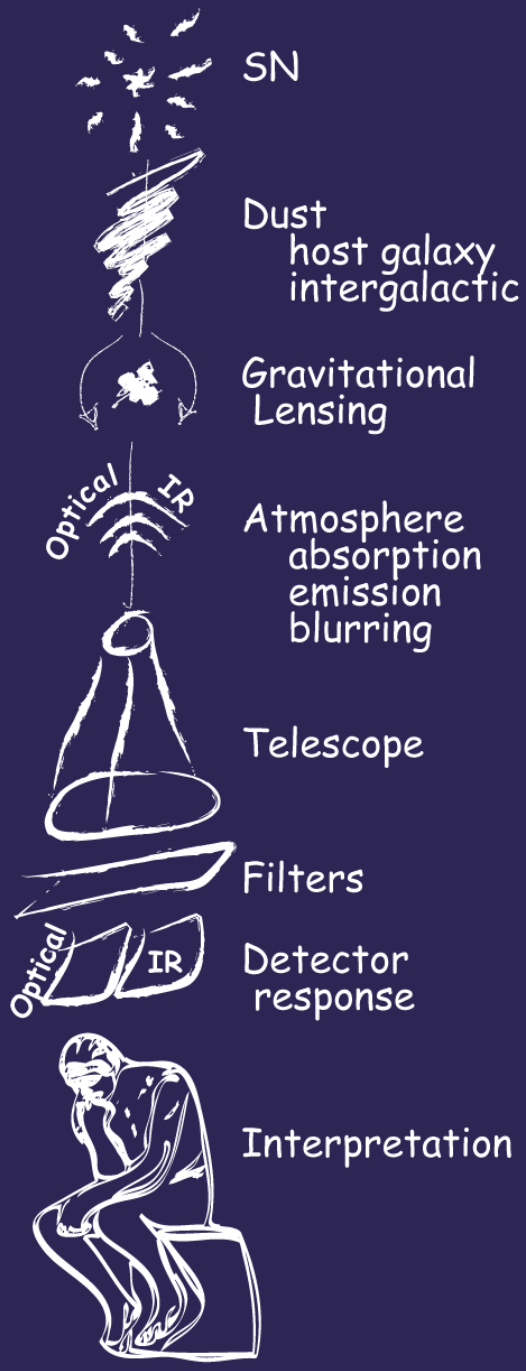
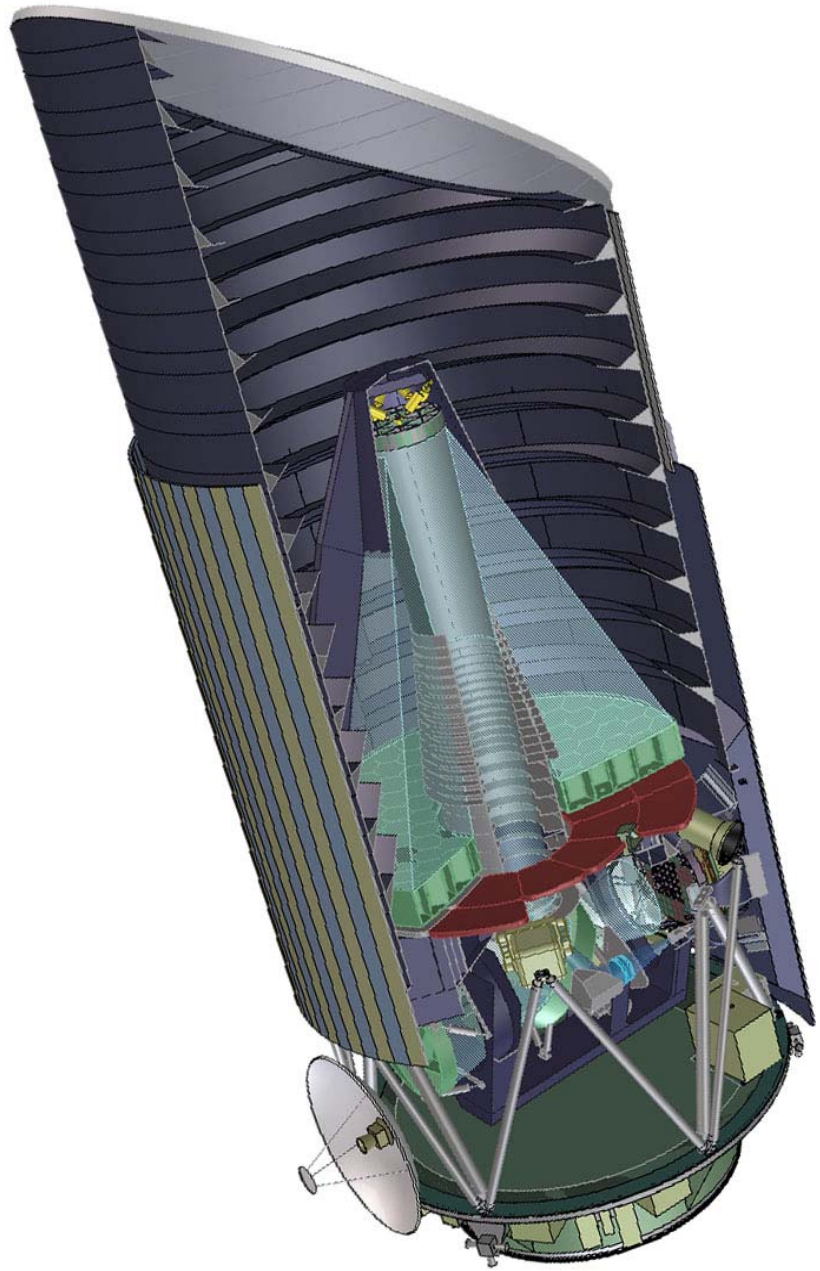
Optical
IR
Detectors
Interpretation
Systematics Limited
0.5
0
−0.5
w_a
−1.2
−1.1
−1
−0.9
−0.8
w_0
68% cl
SNAP[SN]+Planck
$WL_{6000sd,\ n_g=40,\ \delta\gamma=3\%}$ + Planck
SNAP[SN]+Planck+SNAP[WL]$_{1000sd,\ n_g=100\ +\ 6000sd,\ n_g=40,\ \delta\gamma=0.1\%}$

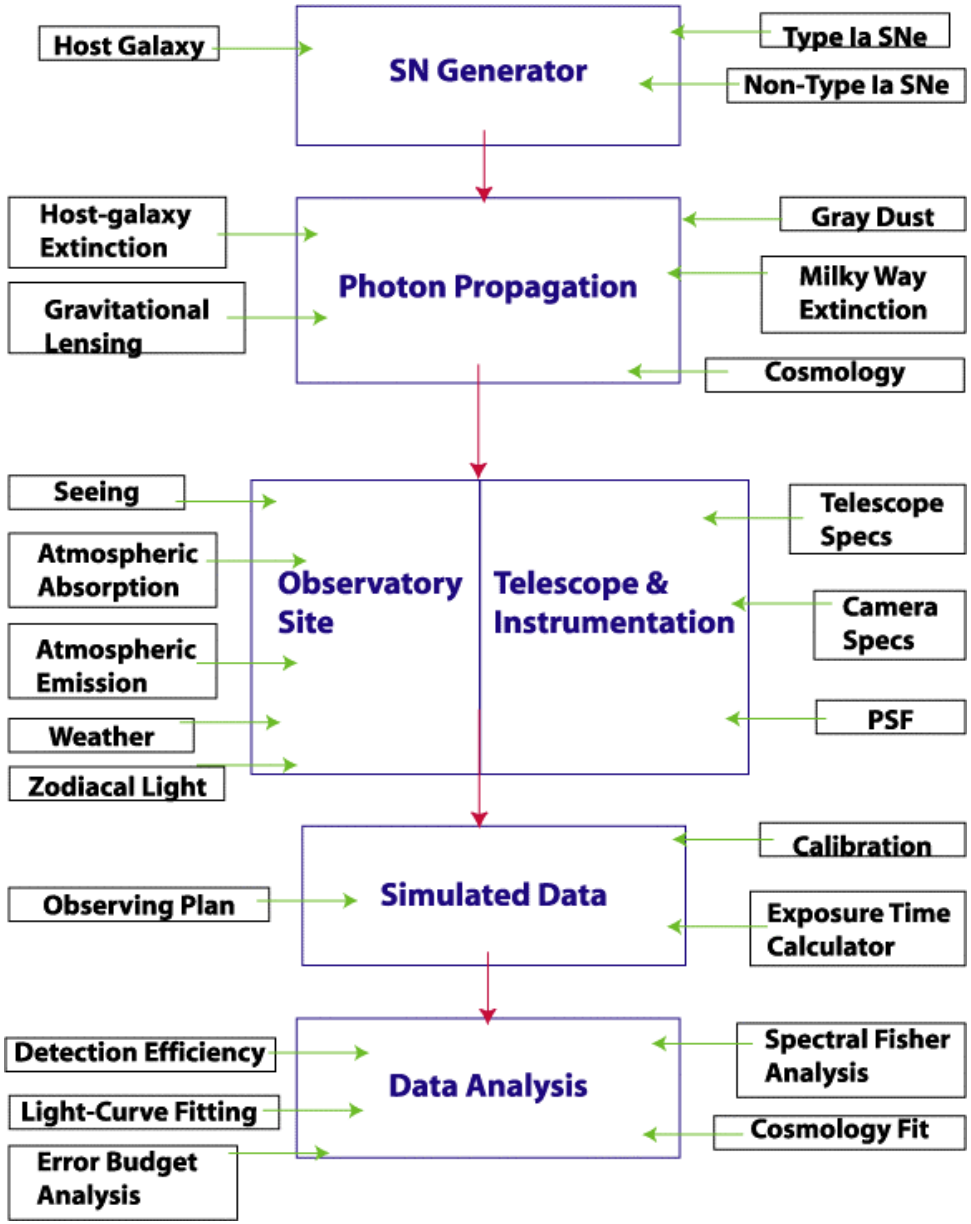

SN
Dust
host galaxy
intergalactic
Gravitational
Lensing
Optical
IR
Atmosphere
absorption
emission
blurring
Telescope
Filters
Optical
IR
Detector
response
Interpretation

Current Concept: Compact & Extremely Simple

- 90 deg Symmetric Focal Plane allows continuous year round science data taking
  - one side always sunward, allowing fixed solar panels hence a rigid spacecraft
  - other side always dark, allowing fixed passive thermal radiator serving sensor array
- Innovative telescope design does IR imaging with room temperature optics
  - three mirror anastigmat has accessible exit pupil and complete cold stop baffling
- Built in end-to-end optical test capability simplifies Integration and Testing
- The fixed telemetry antenna eliminates a major mission risk:
  - no gimbals
  - rigid spacecraft eases ACS task
- No onboard data analysis: all images are downlinked to Earth
  - lossless onboard compression via hardware

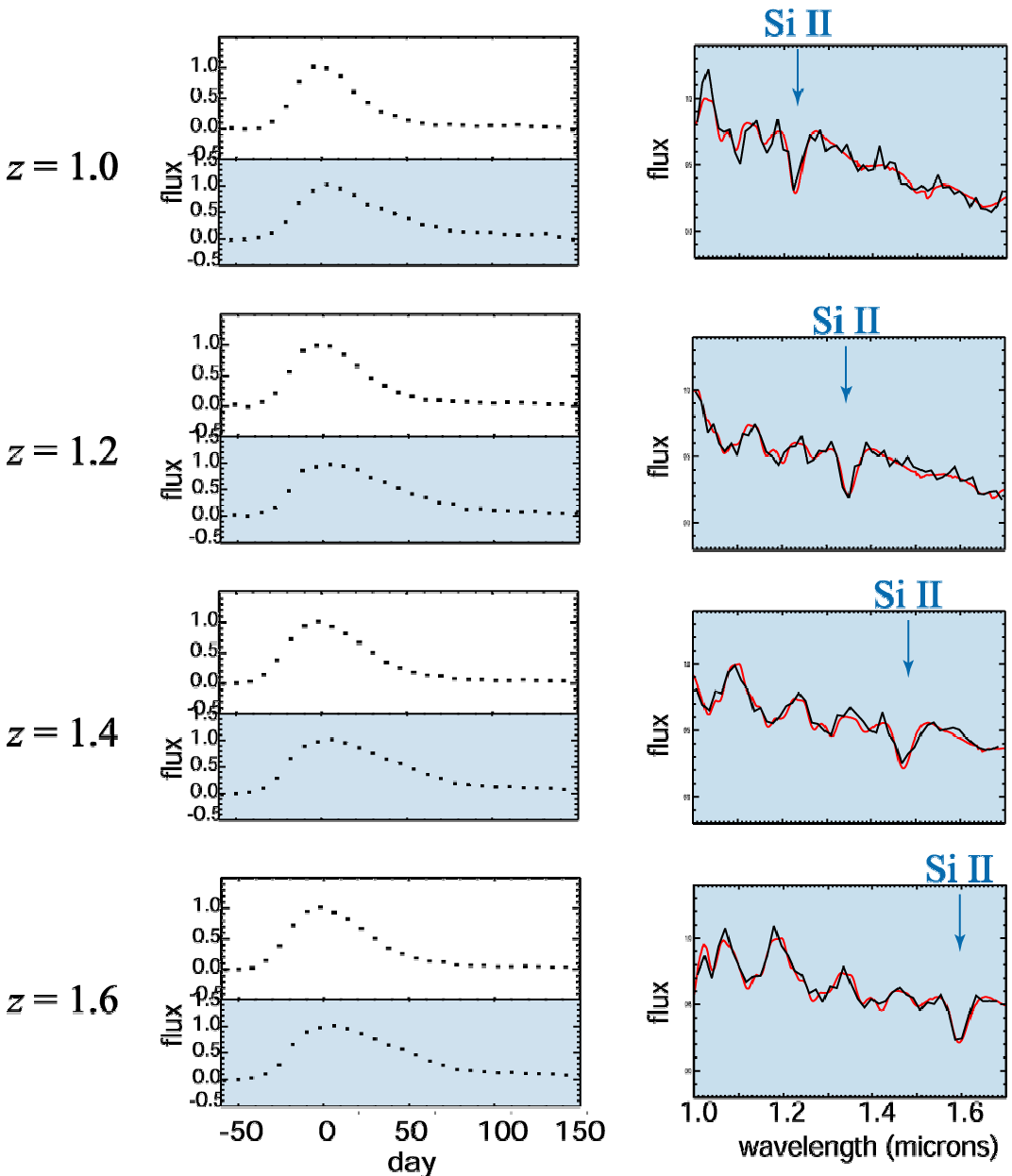


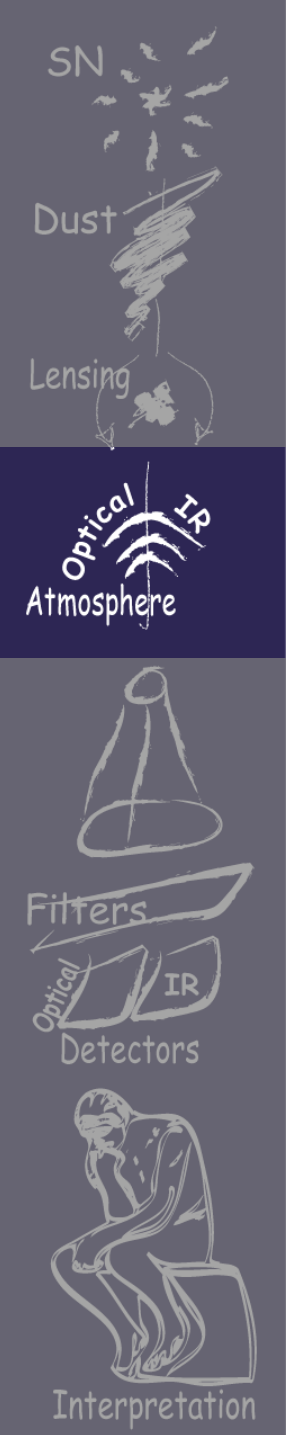
Supernova/Weak Lensing Mission Simulator



…science-driven requirements

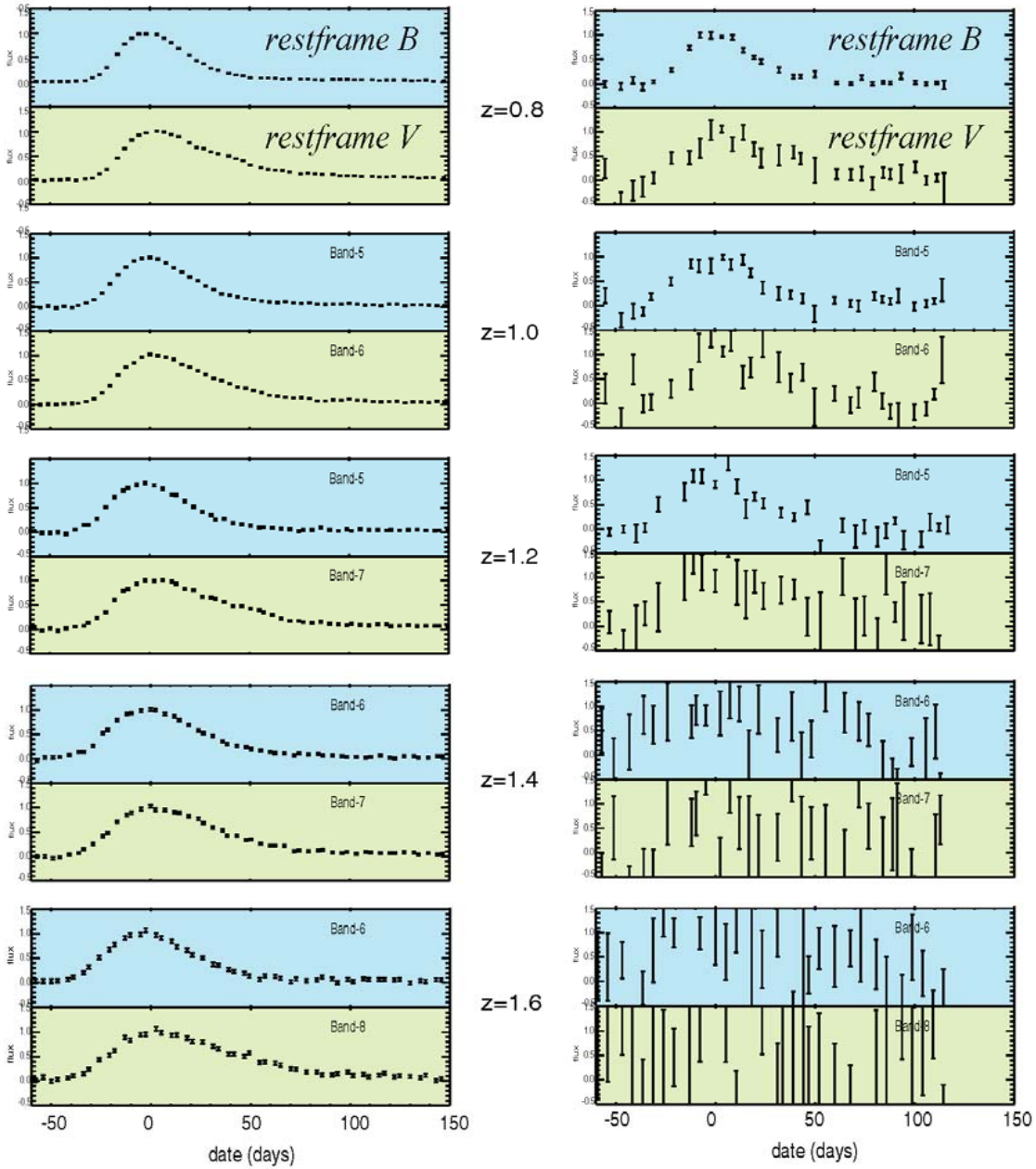
SNAP: Observing supernovae with lightcurves and spectra

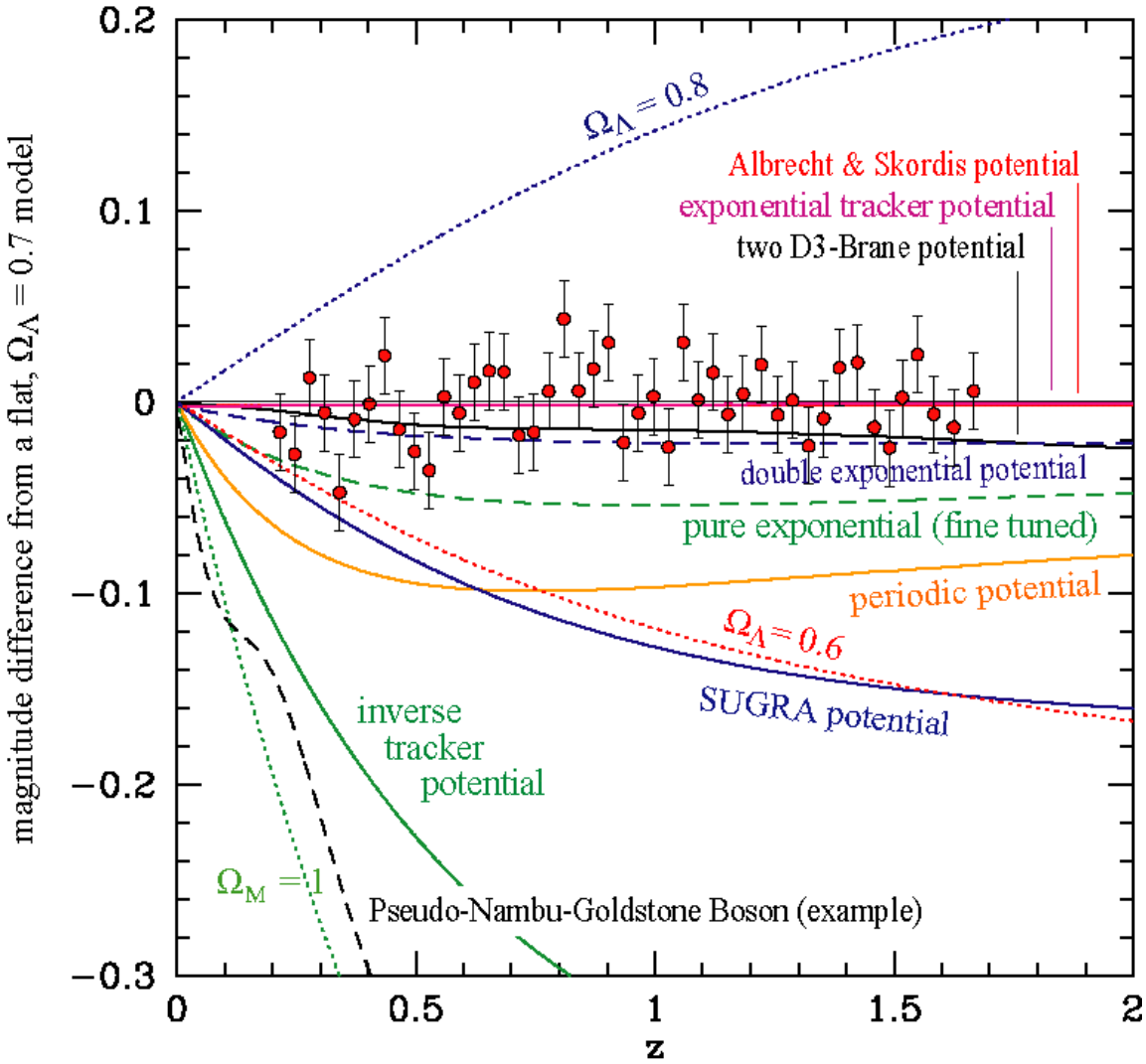




SNAP

8-meter
with NIR camera





based on

Weller & Albrecht (2001)

Requiring complementary measurements of cosmological parameters, Dark Matter, Dark Energy,...

Type Ia supernova calibrated candle:
Hubble diagram to $z = 1.7$

Type II supernova expanding photosphere:
Hubble diagram to $z = 1$ and beyond.

Weak lensing:
Direct measurements of $P(k)$ vs z
Mass selected cluster survey vs z

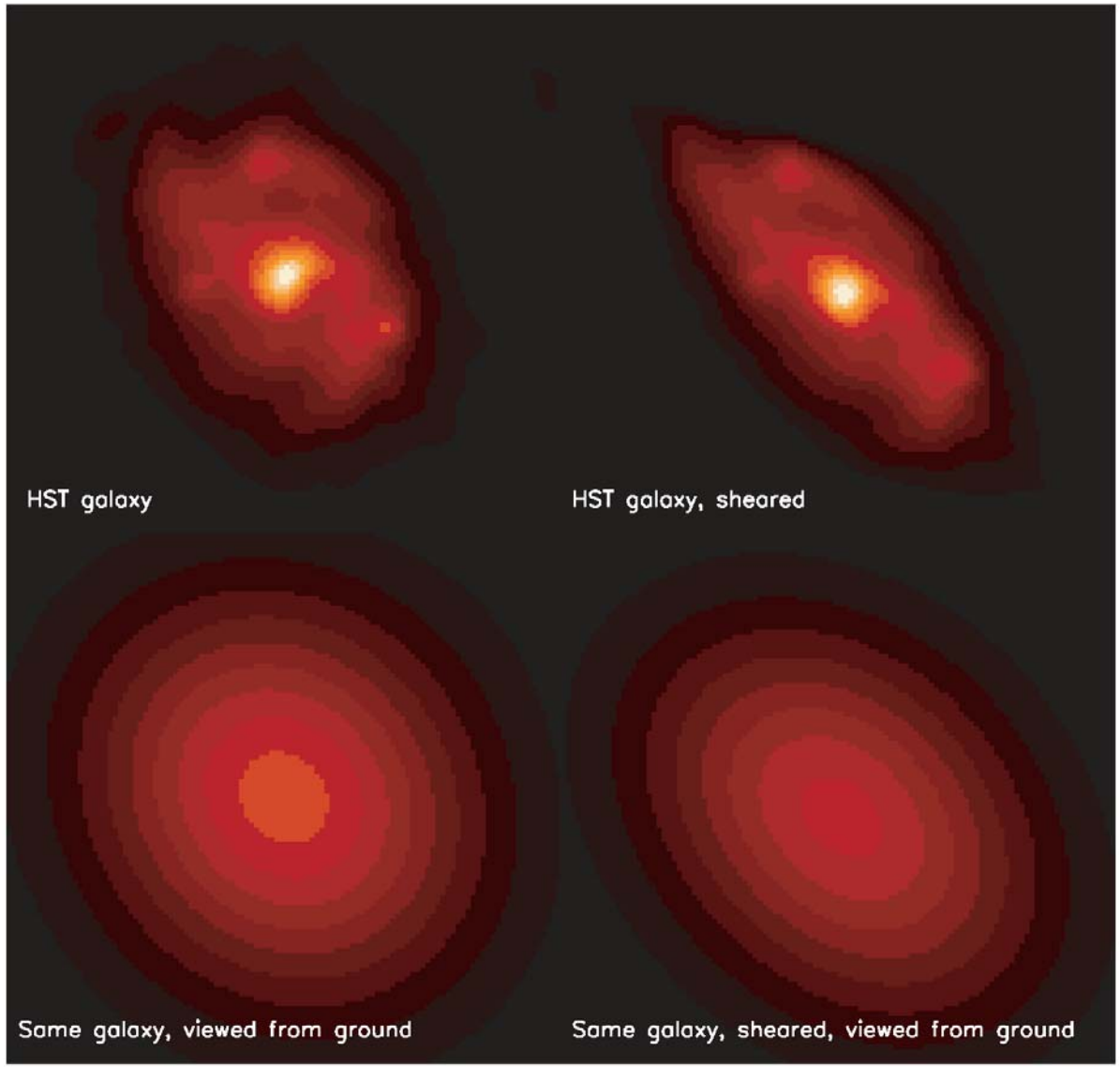
Baryon oscillations:
Redshift range unavailable from ground.

Strong lensing statistics: Ω_Λ
10x gains over ground based optical resolution, IR channels + depth.

Galaxy clustering:
$W(\Theta)$ angular correlation vs

SNAP SuperNova Acceleration Probe

Weak lensing galaxy shear observed from space versus Weak lensing galaxy shear observed from the ground.



Bacon, Ellis, Refregier (2000)

SNAP Surveys

Survey	Area(sq.deg)	Depth(AB mag)	n_{gal}(arcmin^{-2})	N_{gal}
Deep/SNe	15	30.3	250	10^7
Wide	300-1000	28.0	100	$10^{8.5}$
Panoramic	7000-10000	26.7	40-50	10^9

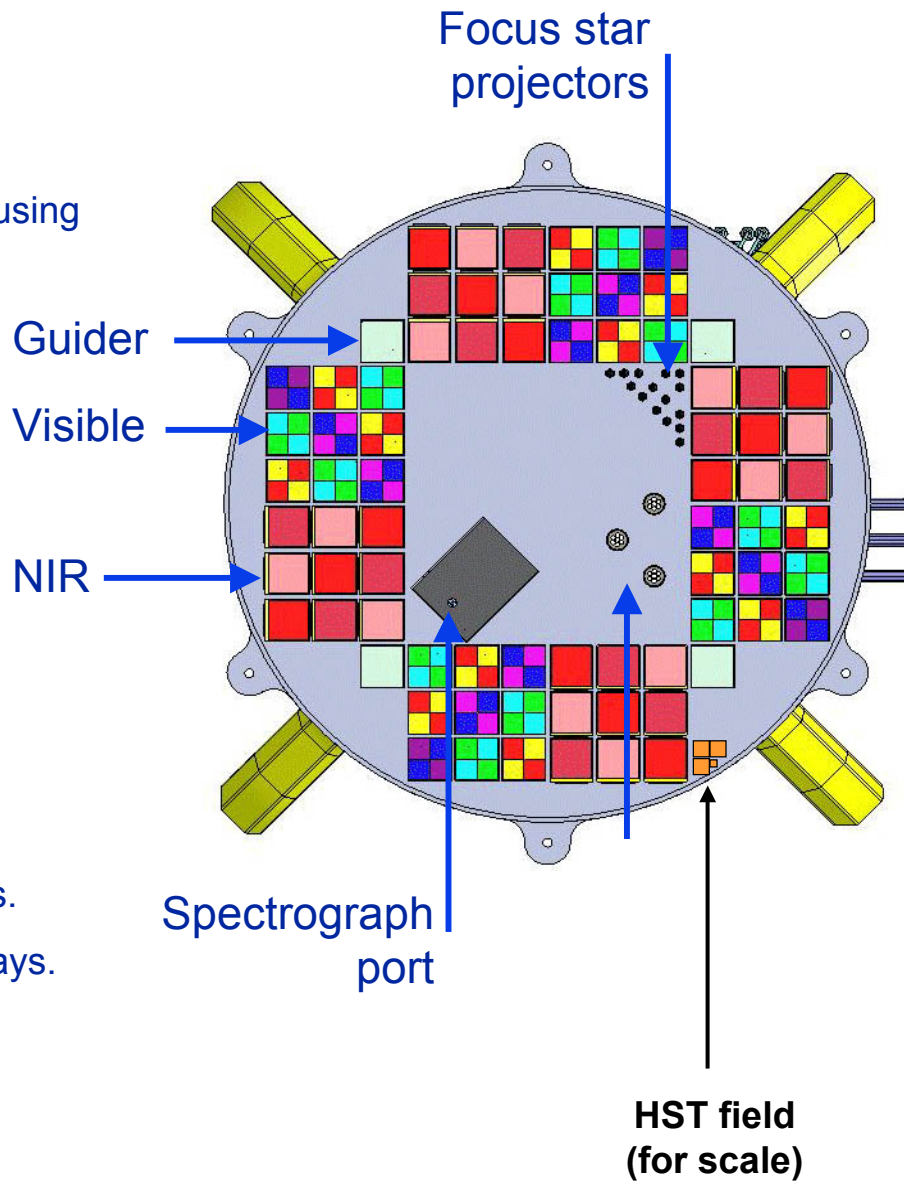
Synergy of Supernovae + Weak Lensing

- Comprehensive: no external priors required!
- Independent test of flatness to 1-2%
- Complementary (SNe + WL only):
  conservative:
    w_0 to ±0.05, variation w' to ±0.12 (*with systematics*) Λ model
    w_0 to ±0.03 variation w' to ±0.06 (*with systematics*) SUGRA model
  Adding panoramic survey and better systematics:
    w_0 to ±0.03, variation w' to ±0.06 (*with systematics*) Λ model
    w_0 to ±0.015 variation w' to ±0.03 (*with systematics*) SUGRA model
- Flexible: Panoramic is available if improved systematics in space warrant greater than 1000 sq. deg.

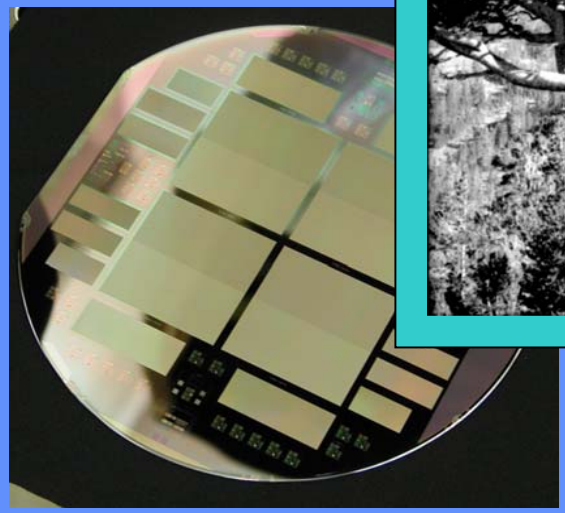
Current Focal Plane

2003:

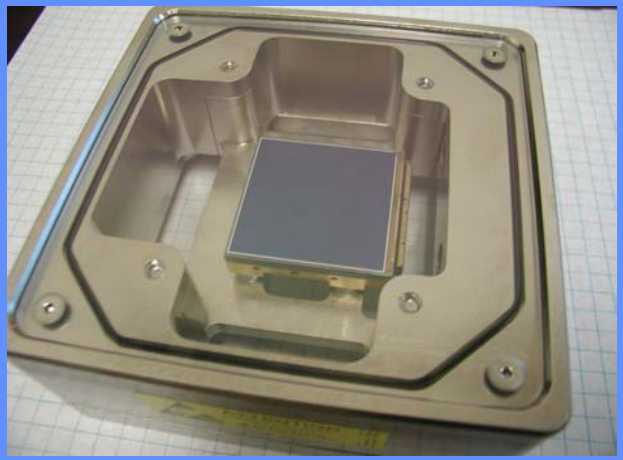
- All instruments coalesced on one focal plane.
  - Common 140K operating temperature.
  - Single focal plane simplifies optics, pointing and focusing
- Photometer sensors in one focal plane, example.
  - 36 2k x 2k, 18 μm HgCdTe NIR sensors.
  - 36 3.5k x 3.5k, 10.5 μm CCD sensors
- Spectrograph mounted to focal plane.
  - Two channel spectrograph with light access port in the focal plane.
  - Objects dropped into spectrograph light port by steering the satellite.
- Fixed filter mosaic
  - Fixed filter array eliminates wheel risk
  - 3 NIR bandpass filter types organized in 3 x 3 arrays.
  - 6 visible bandpass filter types organized in 6 x 6 arrays.
- Guide off the focal plane during exposures.
  - 4 regions of star guider CCDs.
- Telescope I&T and on-orbit calibration hardware



Optical

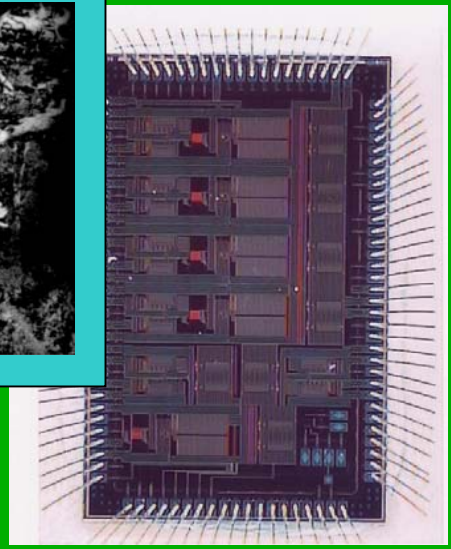


Current wafer with four SNAP CCDs – 3.5kx3.5k, 10.5 μm pixels.

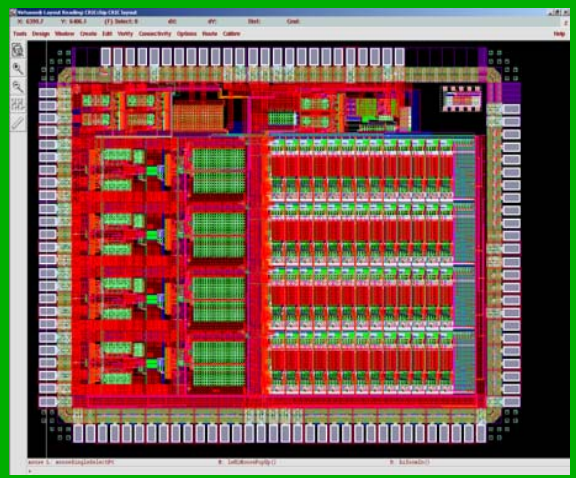


Rockwell 2k x 2k HyVisi

CCD electronics



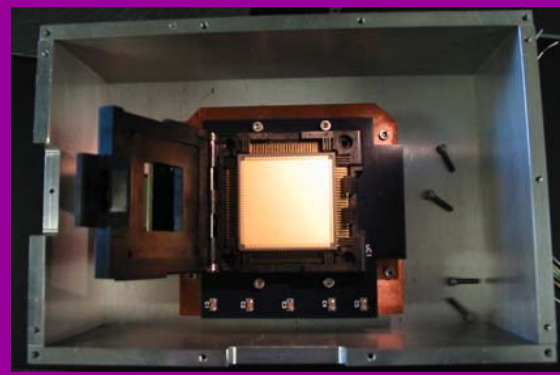
CRIC-I: Four channel dual integration correlated double sampler, operated at 140K.



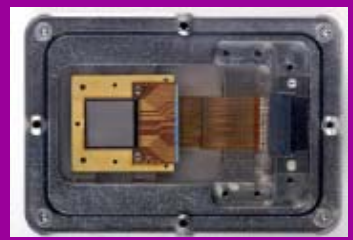
CRIC-II: with 13-b ADC

IR

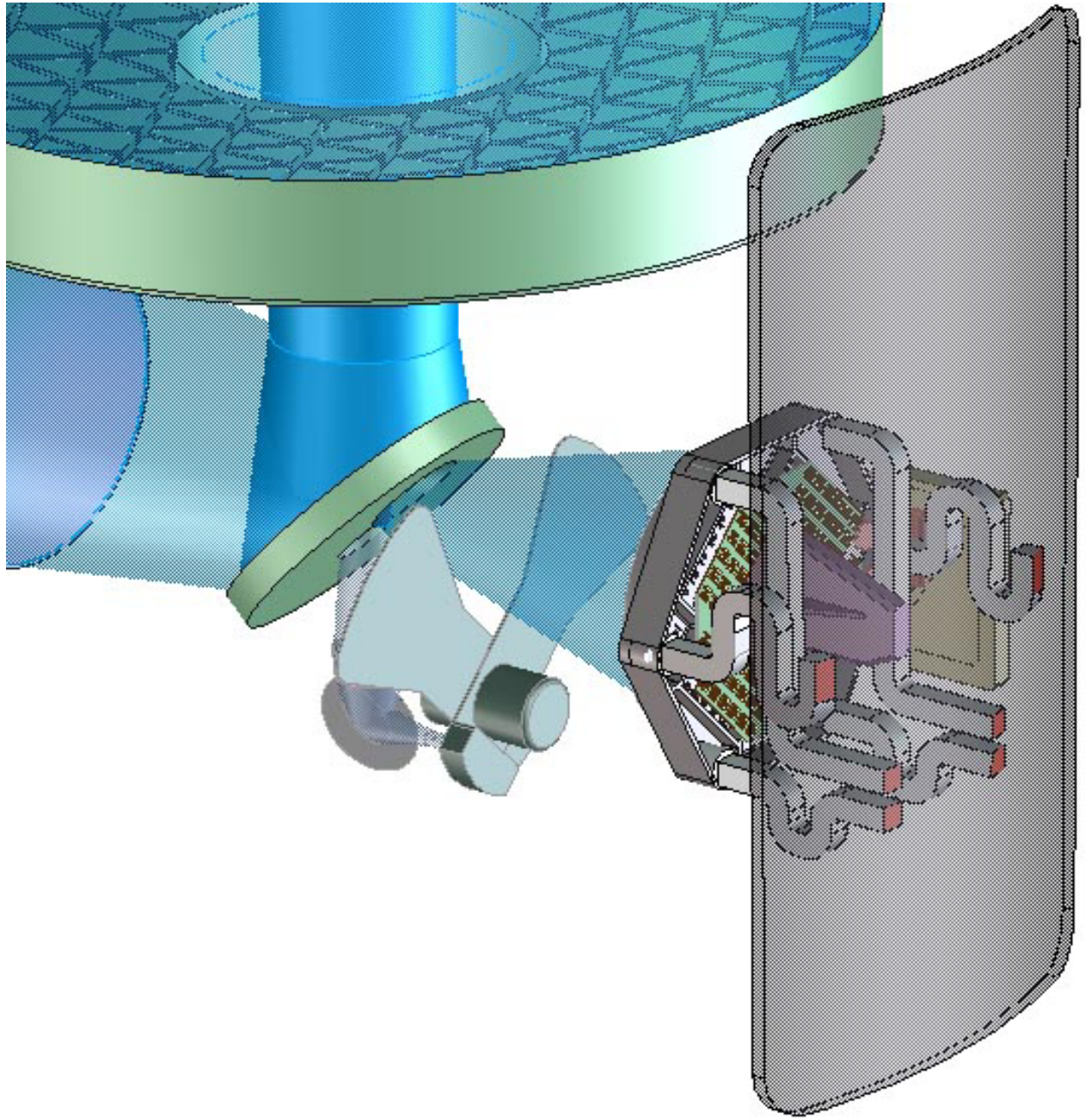
Rockwell 2k x 2k, 1.7 um MCT.



Raytheon 1k x 1k, 1.7 um MCT

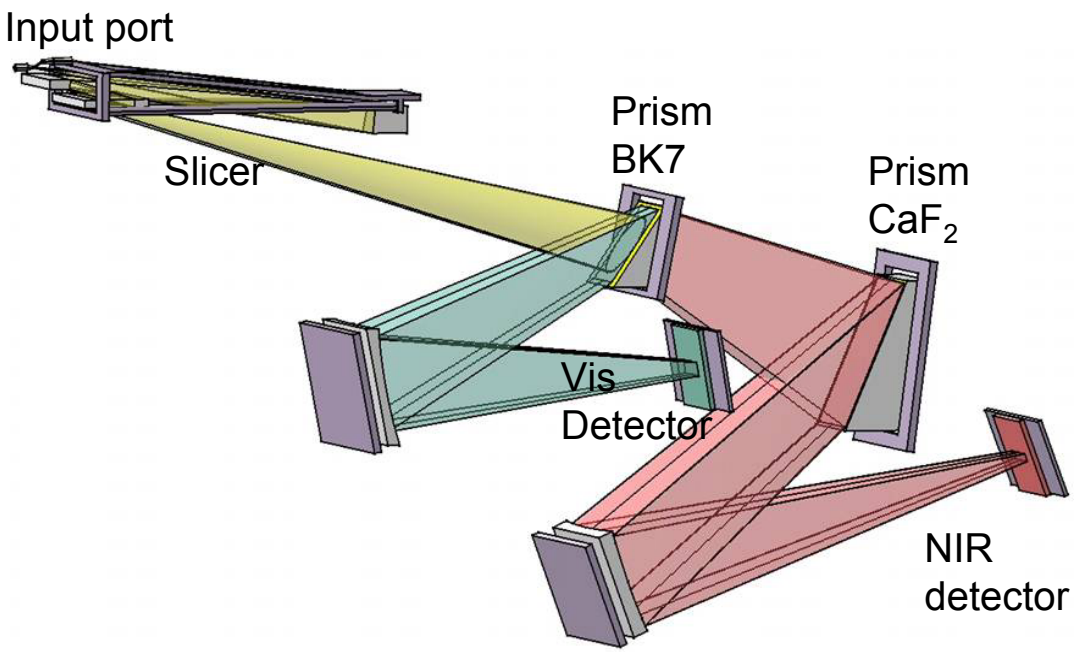


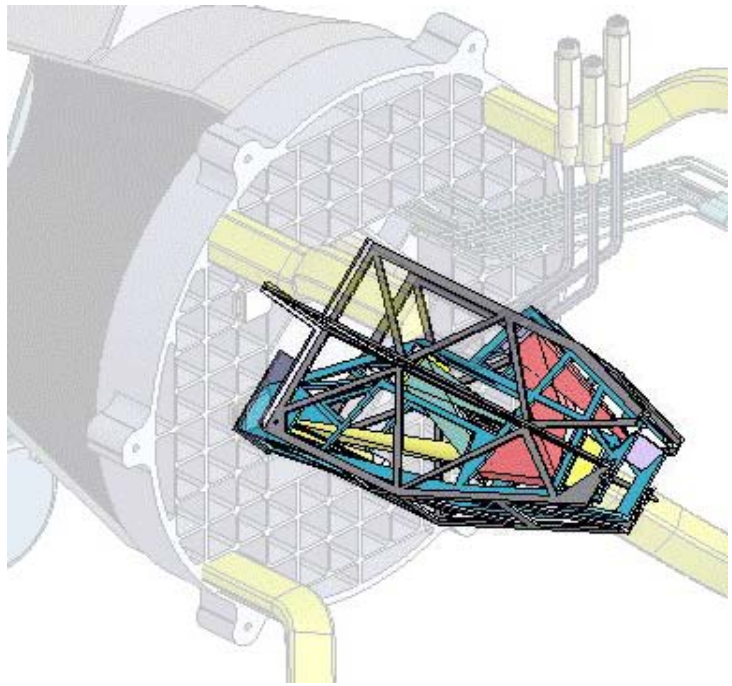
InGaAs 1k x 1k, 1.6 um looks like this.

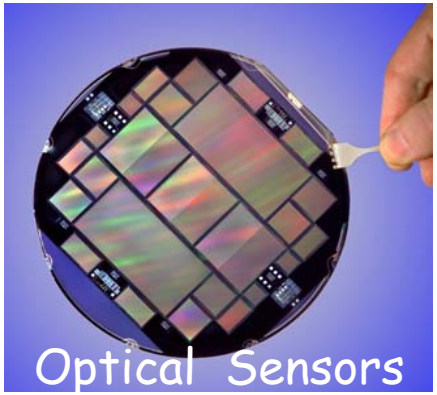


Focal plane - spectrograph

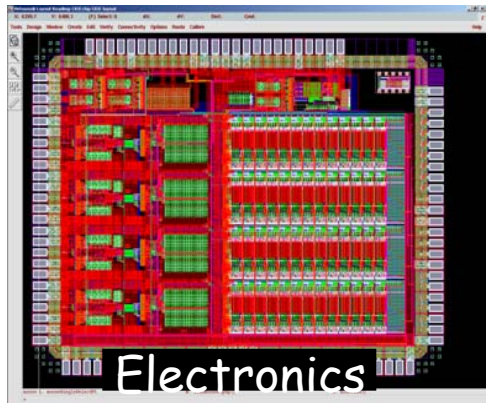
Integral field unit based on an imager slicer.
Input aperture is 3” x 6” – reduces pointing accuracy req.
Simultaneous SNe and host galaxy spectra.
Internal beam split to visible and NIR.

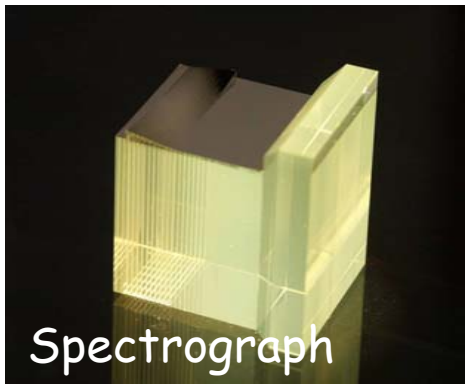


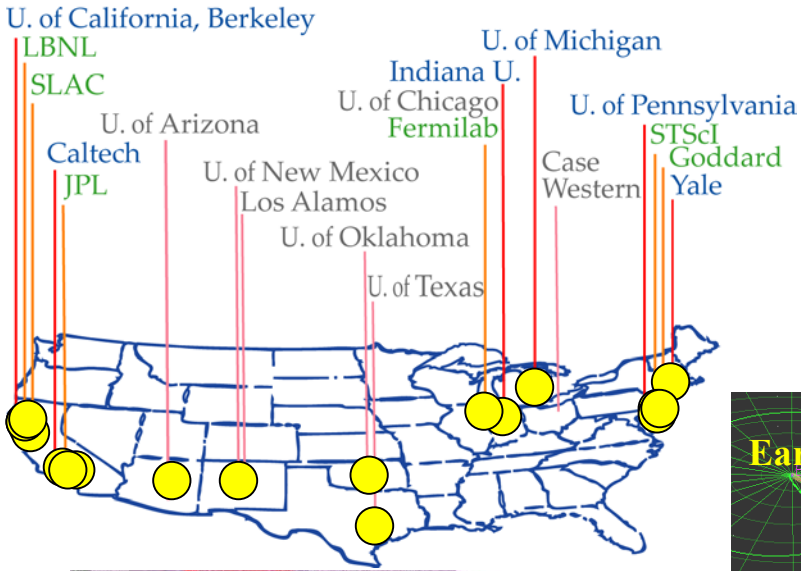



Optical Sensors

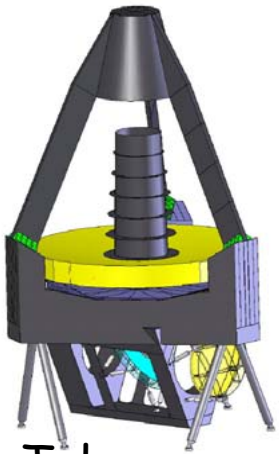

Infra-Red Sensors

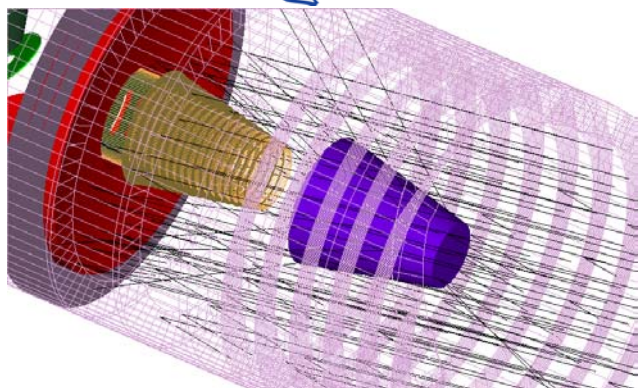

Electronics

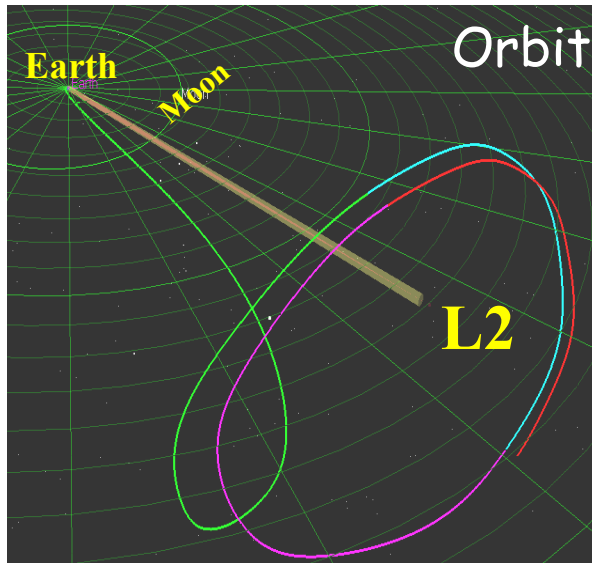

Spectrograph


U. of California, Berkeley
LBNL
SLAC
U. of Arizona
Caltech
JPL
U. of New Mexico
Los Alamos
U. of Oklahoma
U. of Texas
U. of Chicago
Fermilab
Indiana U.
U. of Michigan
Case
Western
U. of Pennsylvania
STScI
Goddard
Yale


Space Optics


Telescope




Earth
Moon
Orbit
L2

SNAP Collaboration

LBNL	**G. Aldering, C. Bebek, W. Carithers, C. Day, R. DiGennaro, S. Deustua†, D. Groom, M. Hoff, S. Holland, D. Huterer†, A. Karcher, A. Kim, W. Kolbe, W. Kramer, B. Krieger, G. Kushner, N. Kuznetsova, R. Lafever, J. Lamoureux, M. Levi, E. Linder, S. Loken, R. Miquel, P. Nugent, H. Oluseyi†, N. Palaio, S. Perlmutter, N. Roe, A. Spadafora, H. Von Der Lippe, J-P. Walder, G. Wang**
UC Berkeley	**M. Bester, E. Commins, G. Goldhaber, H. Heetderks, P. Jelinsky, M. Lampton, D. Pankow, M. Sholl, G. Smoot**
Caltech	**R. Ellis, R. Massey†, A. Refregier†, J. Rhodes, R. Smith, K. Taylor**
Fermi National Laboratory	**J. Annis, F. DeJongh, S. Dodelson, T. Diehl, J. Frieman, L. Hui, S. Kent, P. Limon, J. Marriner, H. Lin, J. Peoples, V. Scarpine, A. Stebbins, C. Stoughton, D. Tucker, W. Wester**
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IN2P3 (France)	**P. Astier, E. Barrelet, A. Bonissent, A. Ealet, D. Fouchez†, R. Pain, G. Smadja, A. Tilquin, D. Vincent**
LAM (France)	**S. Basa, R. Malina, A. Mazure, E. Prieto**
University of Michigan	**B. Bigelow, M. Brown, M. Campbell, D. Gerdes, W. Lorenzon, T. McKay, S. McKee, M. Schubnell, G. Tarle, A. Tomasch**
University of Pennsylvania	**G. Bernstein, L. Gladney, B. Jain, D. Rusin**
University of Stockholm	**R. Amanullah, L. Bergström, A. Goobar, E. Mörtsell**
SLAC	**W. Althouse, R. Blandford, W. Craig, S. Kahn, M. Huffer, P. Marshall**
STScI	**R. Bohlin, A. Fruchter**

NASA Centers on the Concept Studies with the SNAP Collaboration

JPL

C. Beichman, E. Cohen, D. Cole, P. Eisenhardt, M. Frerking, A. Gerber, M. Herring, C. Lawrence, J. Rhodes, M. Seiffert, D. Stern, M. Werner

GSFC

D. Fixsen, J. Gardner, M. Greenhouse, R. Hill, G. Hinshaw, R. Kimble, J.Mather, S. Moseley, W. Oegerle, B. Rauscher, B. Woodgate

Instrumentation Papers in the Last Year

Focal Plane: C. Bebek, et al, Proc. SPIE 5164 (2003) SNAP Satellite Focal Plane Development
C. Bebek, et al, Proc. SPIE 4854, SNAP Focal Plane

CCD: S. Holland, et al, IEEE Trans. Electron Dev. 50, Fully Depleted, Back-Illuminated Charge-Coupled Devices Fabricated on High-Resisitivity Silicon
C. Bebek et al. Proc. SPIE 5167, Fully depleted back-illuminated p-channel CCD development
C. Bebek, et al. Proc. SPIE 4669 (2003) Proton radiation damage in high-resistivity n-type silicon CCDs
C. Bebek, et al. IEEE Trans Nucl. Sci. vol. 49, 1221, Proton Radiation Damage in P-Channel CCDs Fabricated on High-Resistivity Silicon
A. Karcher et al, IEEE Trans. Nucl. Sci. Measurement of Lateral Charge Diffusion in Thick, Fully Depleted, Back-illuminated CCDs, submitted for publication.

IR: G. Tarle et al, Proc SPIE 4850, SNAP Near Infrared Detectors

Spectrograph: A. Ealet, et al. Proc SPIE (2003), An integral field spectrograph for SNAP supernova studies

Electronics: J.P. Walder, IEEE Trans Nucl. Sci., submitted for publication

Calibration: S. Deustua et al, SPIE 2003, Calibrating SNAP

Telescope: M. Lampton et al, Proc. SPIE 5166, 2003, SNAP Telescope

SNAP Science Papers in the Last Year

Supernova / Acceleration Probe: A Satellite Experiment to Study the Nature of the Dark Energy, PASP, submitted (astro-ph/0405232)

Overview of the SuperNova/Acceleration Probe (SNAP) G. Aldering et al., SPIE 4835

Wide-Field surveys from the SNAP Mission, A. Kim et al., SPIE 4836

Importance of SNe at z>1.5, E. Linder, D. Huterer, Phys.Rev. D67

Frieman, Huterer, Linder, & Turner: Probing Dark Energy with Supernovae: Exploiting Complementarity with the CMB Phys. Rev. D 67, 083505 (2003).

Weak Lensing from Space I: Prospects for The Supernova/Acceleration Probe, Rhodes et al. Astro. Phys. 20, 377 (2004).

Weak Lensing from Space II: Dark Matter Mapping, Massey et al.

Weak Lensing from Space III: Cosmological Parameters, Refregier et al.

Effects of Systematic Uncertainties on the Supernova Determination of Cosmological Parameters, A. Kim, et al., MNRAS

Dark Energy Constraints from Weak Lensing Cross-Correlation Cosmography, Bernstein & Jain, ApJ 600, 17 (2004)

Cross-correlation Tomography: Measuring Dark Energy Evolution with Weak Lensing, Jain & Taylor, PRL 91, 2003

Baryon Oscillations as a Cosmological Probe, Linder, PRD 68, 083504 (2003)

Dark Energy, Expansion History of the Universe, and SNAP, Linder, AIP Conf.Proc. 655, 193 (2003)

Gravitational Lensing by Cosmic Strings in the Era of Wide-Field Surveys, Huterer & Vachaspati, PRD 68, 041301 (2003)

Joint Galaxy-Lensing Observables and the Dark Energy, Hu & Jain, submitted to PRD

Cosmological parameters from lensing power spectrum and bispectrum tomography, Takada & Jain, submitted to MNRAS

Strong Gravitational Lensing and Dark Energy Complementarity, Linder, submitted to PRD

Testing the Cosmological Constant as a Candidate for Dark Energy, Kratochvil, Linde, Linder, & Shmakova, sub. to JCAP

Evolution of SNAP/JDEM: Reviews/Studies/Milestones

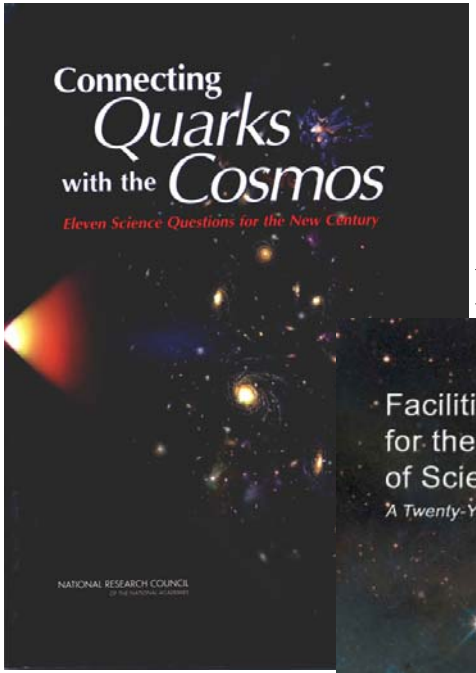
1998 Discovery of the acceleration of the universe and dark energy using supernovae.

2000 Confirmation of dark energy using cosmic microwave background measured from balloons.

2003 Confirmation of dark energy using cosmic microwave background measured from space (WMAP).

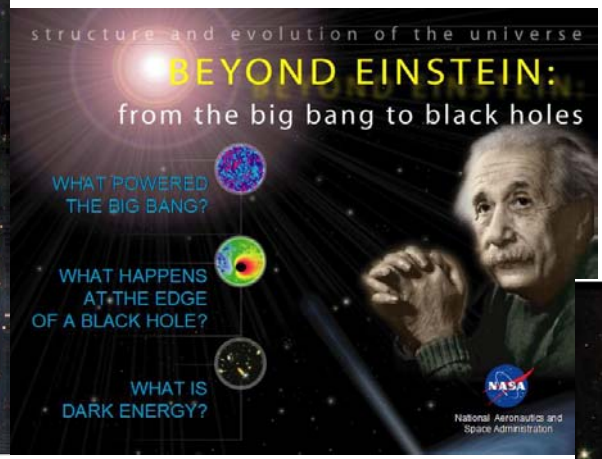
Nov 1999 Original SNAP proposal submitted to DOE
Mar 2000 DOE/NSF SAGENAP committee recommends SNAP R&D
Sep 2000 NASA Structure and Evolution of the Universe (SEU)
Dec 2000 National Academy of Sciences Committee on Astro. & Astrophysics
Jan 2001 DOE-HEP Review R&D (SNAP is uniquely able)
Mar 2001 DOE High Energy Physics Advisory Panel (HEPAP)
Jun 2001 NASA Integrated Mission Design Center (determines feasibility)
July 2001 National Academy of Sciences, Committee on Physics of the Universe
Dec 2001 NASA/SEU Strategic Planning Panel
Dec 2001 NASA Instrument Synthesis & Analysis Lab
Jan 2002 DOE subpanel report: High Energy Physics Long Range Planning
Mar 2002 DOE/NSF SAGENAP committee update
Apr 2002 National Academy of Sciences: Physics of the Universe report
July 2002 DOE Office of Science R&D Review (Lehman)
Dec 2002 JPL Team-X Study (studies potential NASA cost)
Jan 2003 NASA releases SEU roadmap: Beyond Einstein
Feb 2003 DOE High Energy Physics Facilities Prioritization Panel
Feb 2003 SNAP R&D in the DOE budget
Mar 2003 DOE High Energy Physics panel releases Facilities 20 Year Roadmap
Nov 2003 JDEM Announcement from DOE & NASA
Nov 2003 Secretary of Energy's 20-year Facilities Plan
Nov 2003 Technical Review of SNAP (could be launched ~2011)
May 2004 OSTP Strategic Plan (JDEM top recommendation)

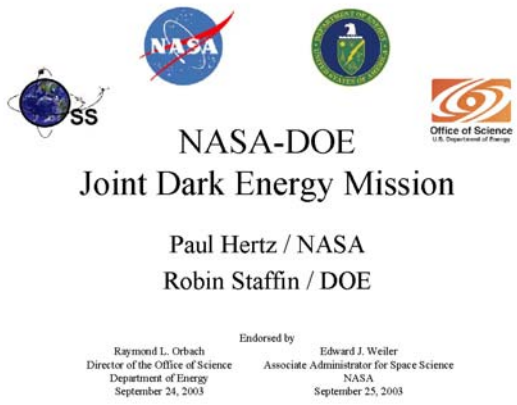
National Acadamy of Sciences



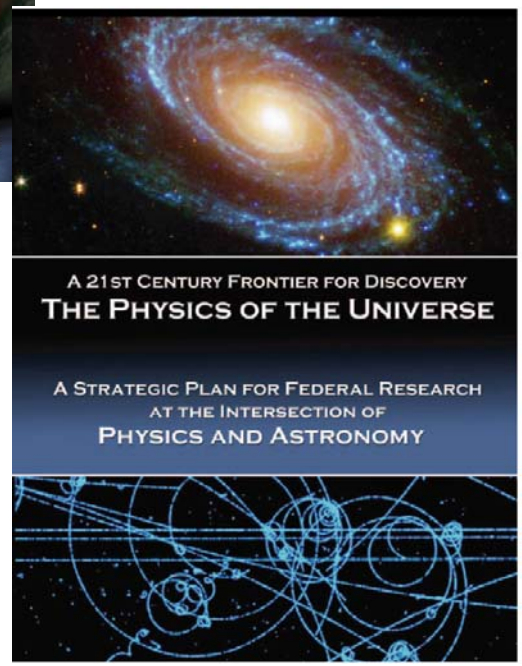
Department of Energy

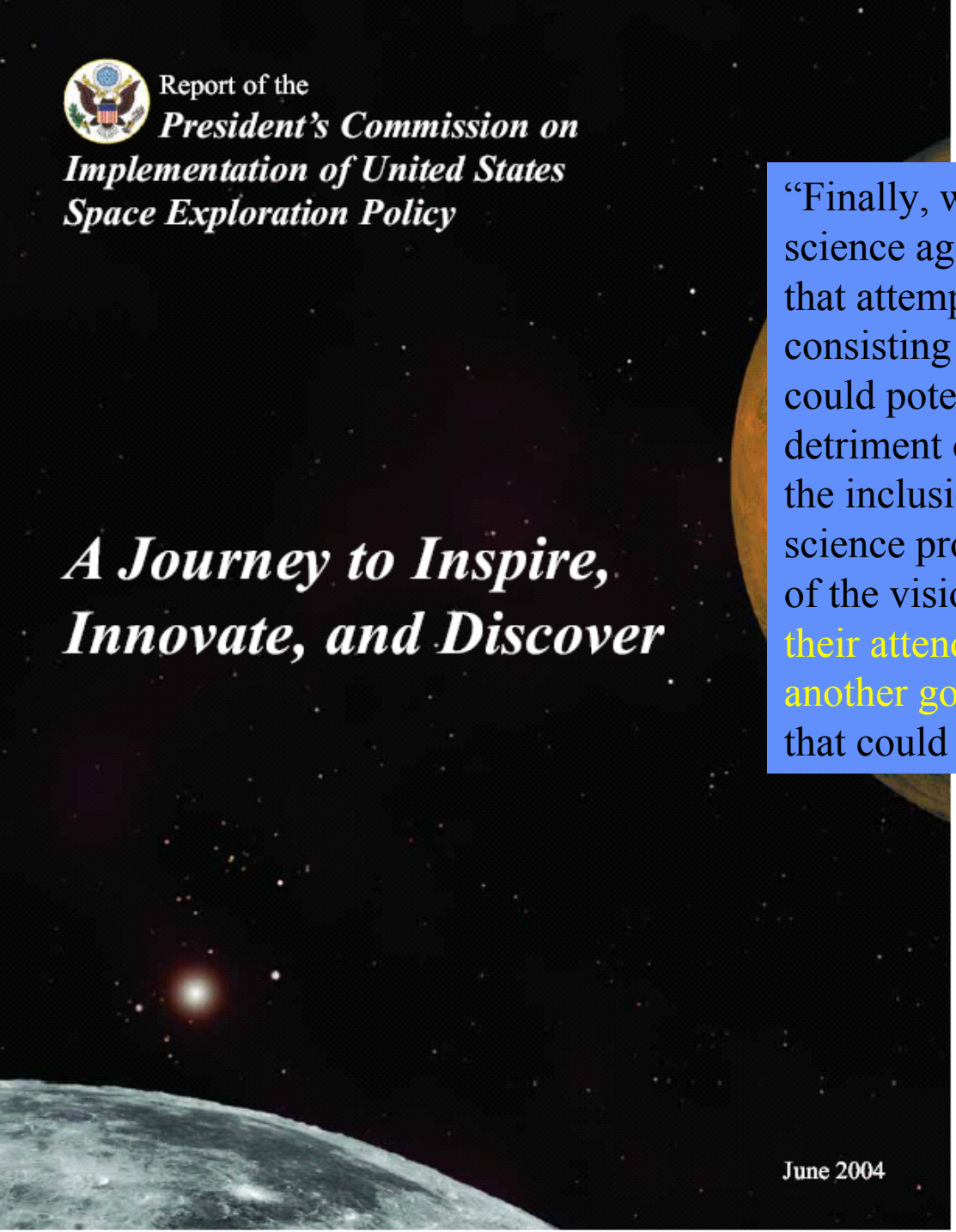
NASA





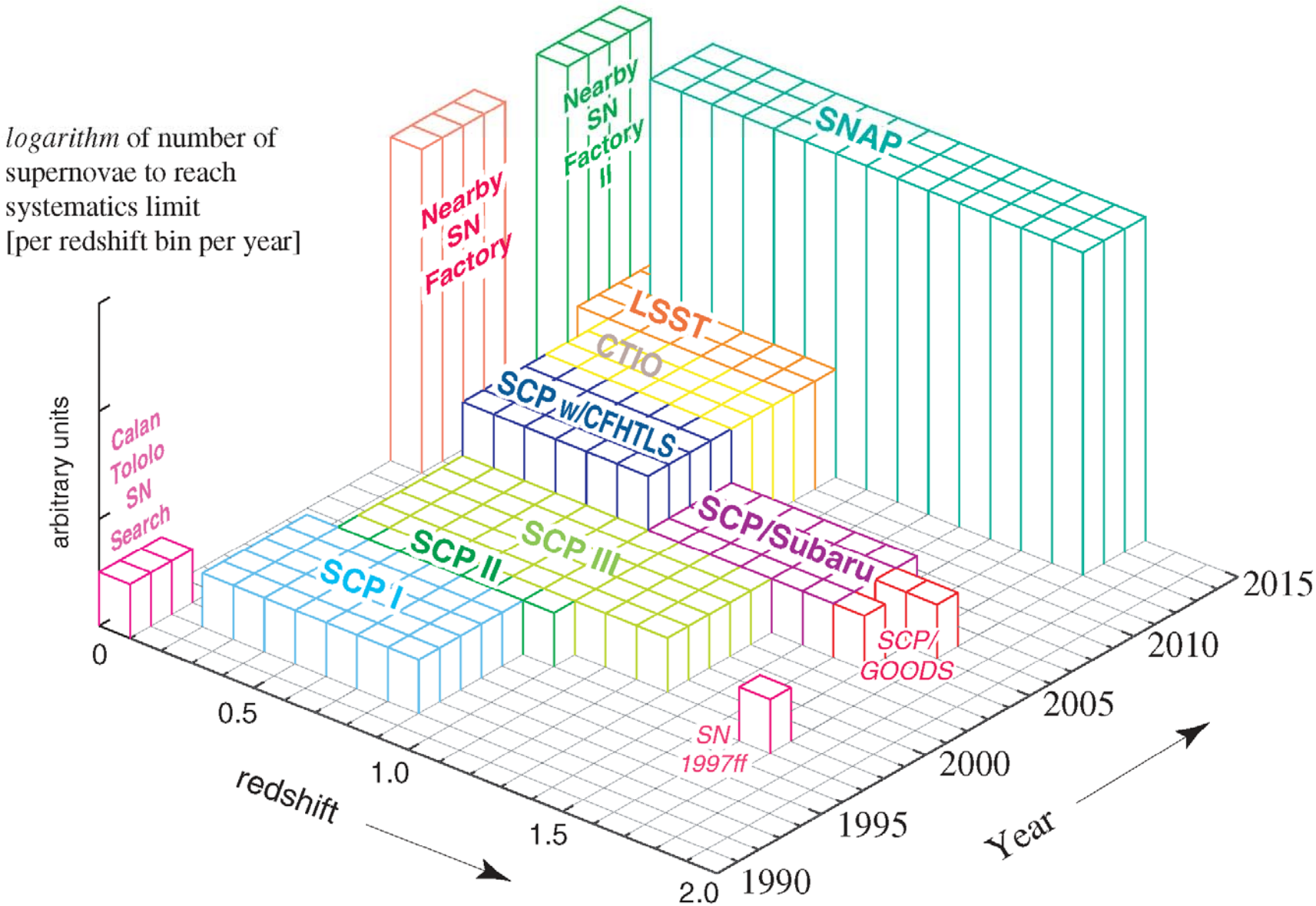
OSTP





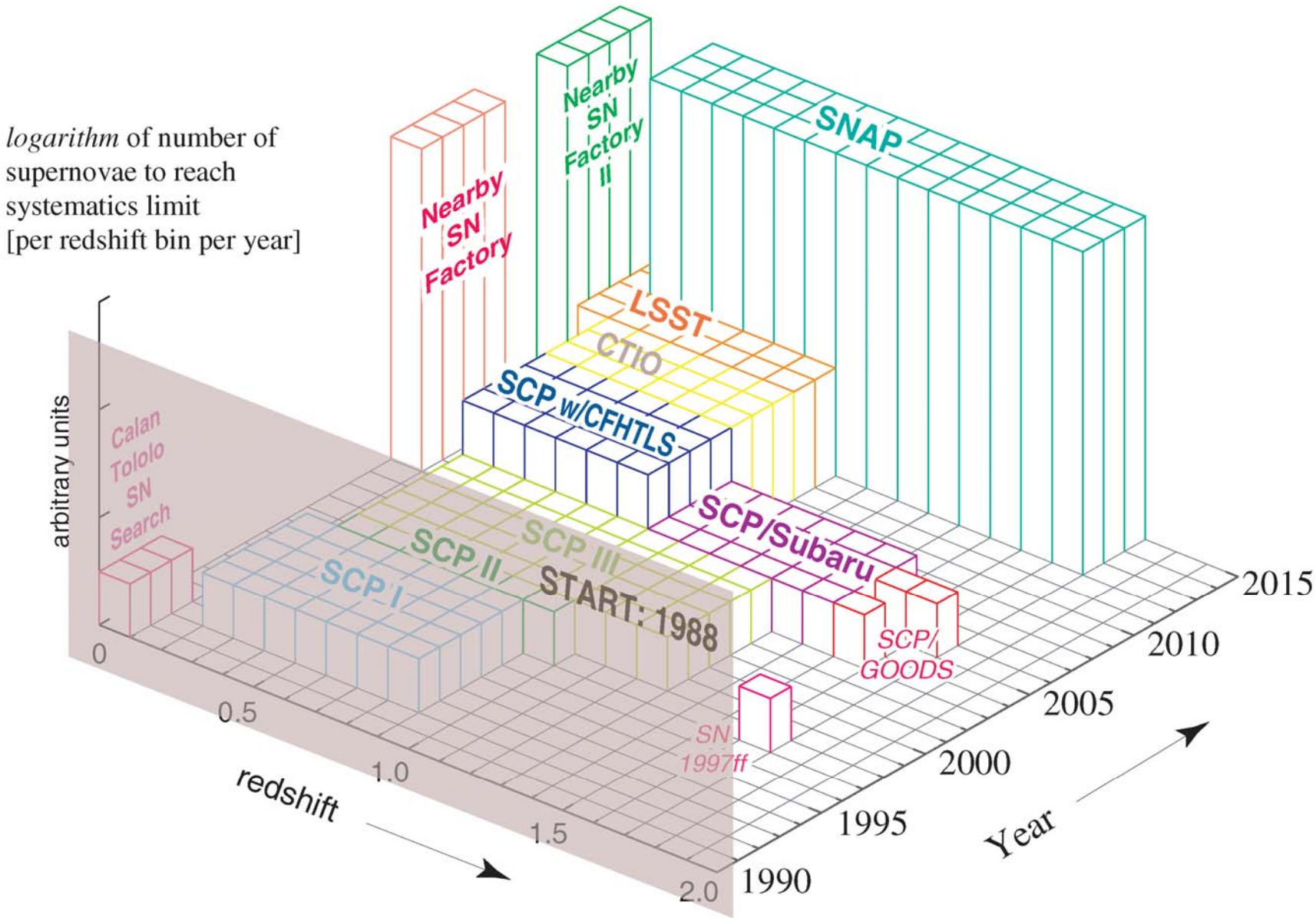
"Finally, while favoring an inclusive future science agenda for the nation, we recognize that attempts to implement a sweeping program consisting of even the most meritorious science could potentially defocus the vision to the detriment of all science. If it is determined that the inclusion of specific highly regarded science programs hampers the implementation of the vision, then such programs, along with their attendant budgets, should be transferred to another government agency or organization that could capably implement them."

The Context of the Supernova Cosmology Work at LBNL



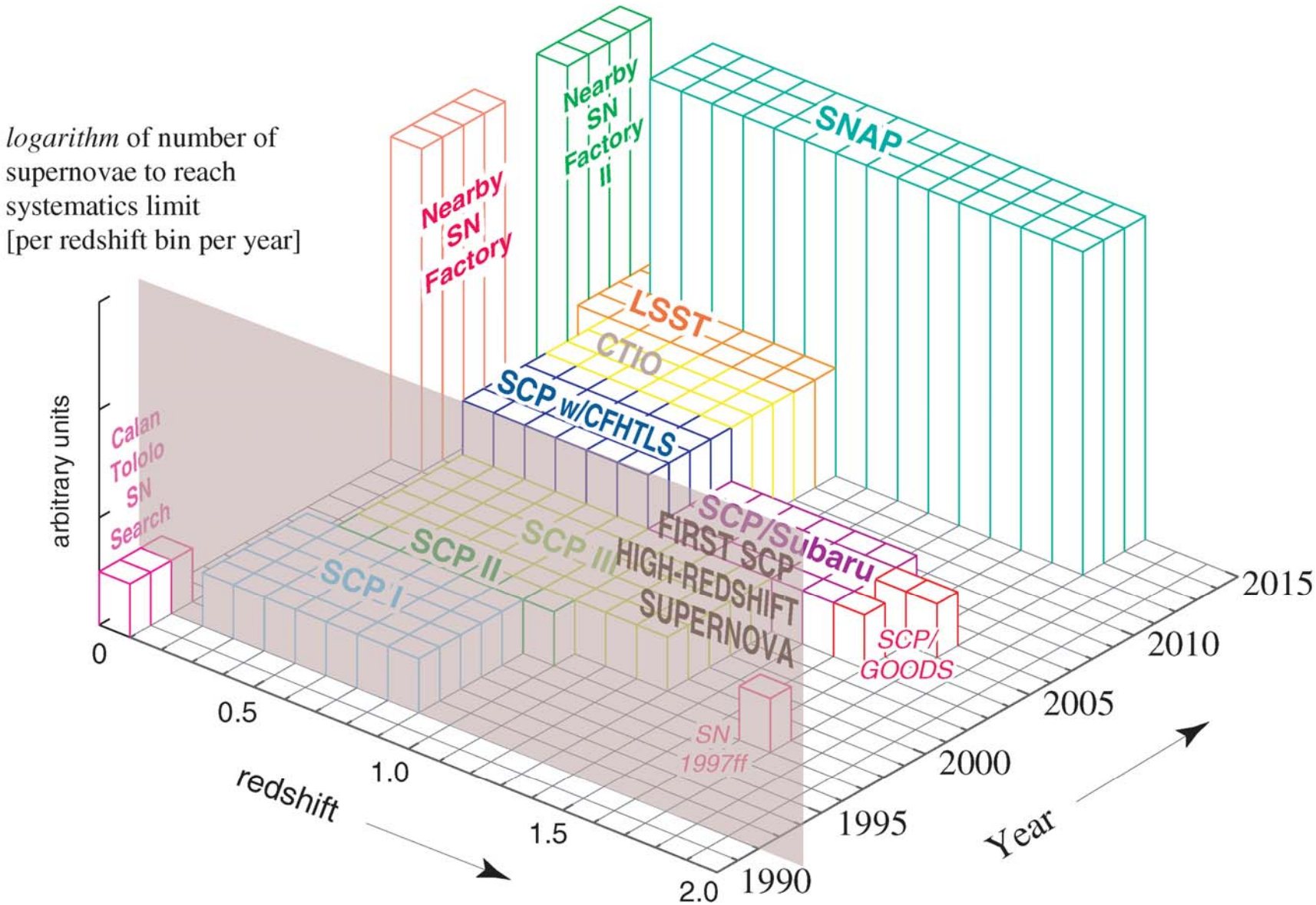
SCP = Supernova Cosmology Project

The Context of the Supernova Cosmology Work at LBNL



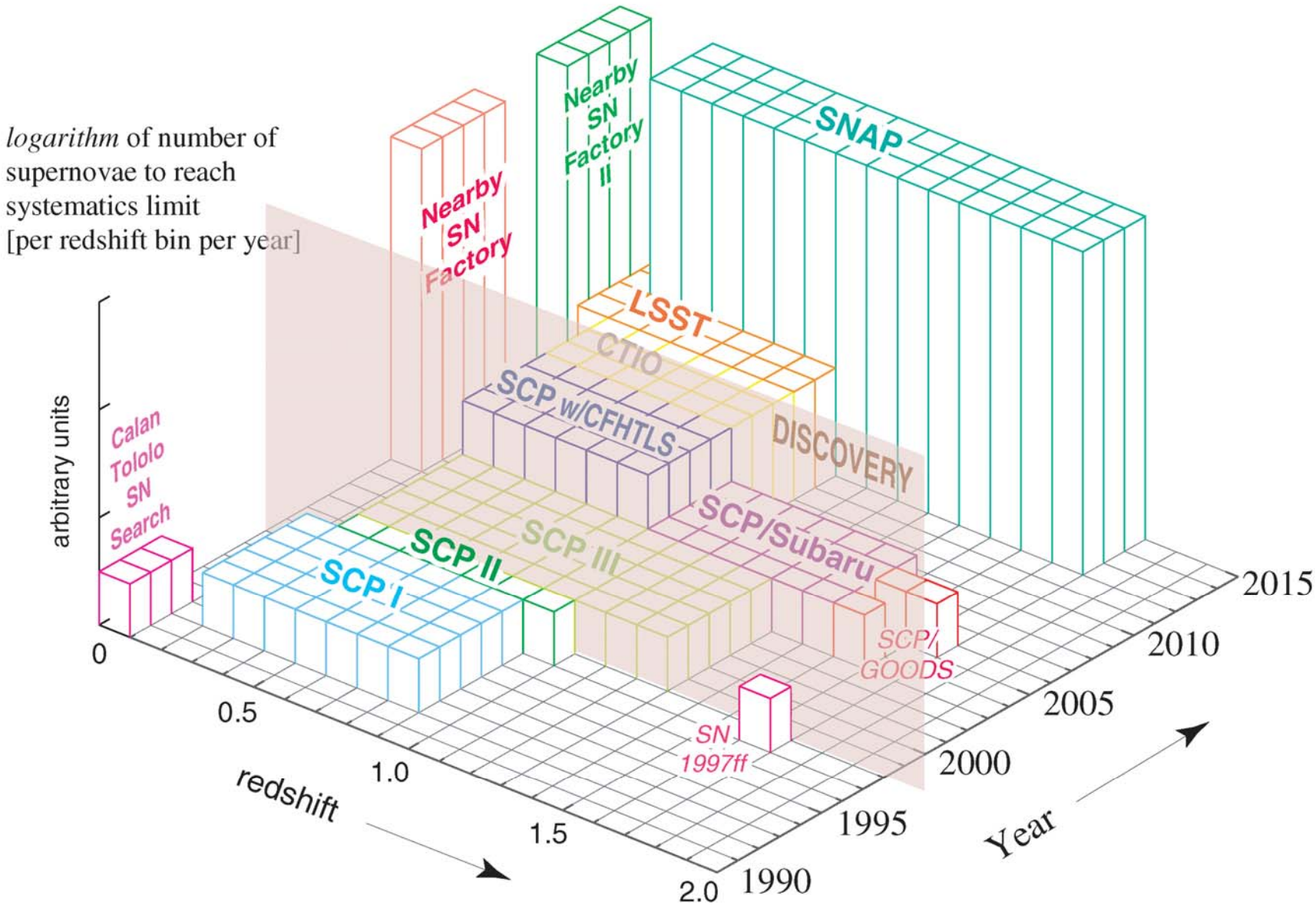
SCP = Supernova Cosmology Project

The Context of the Supernova Cosmology Work at LBNL



SCP = Supernova Cosmology Project

The Context of the Supernova Cosmology Work at LBNL



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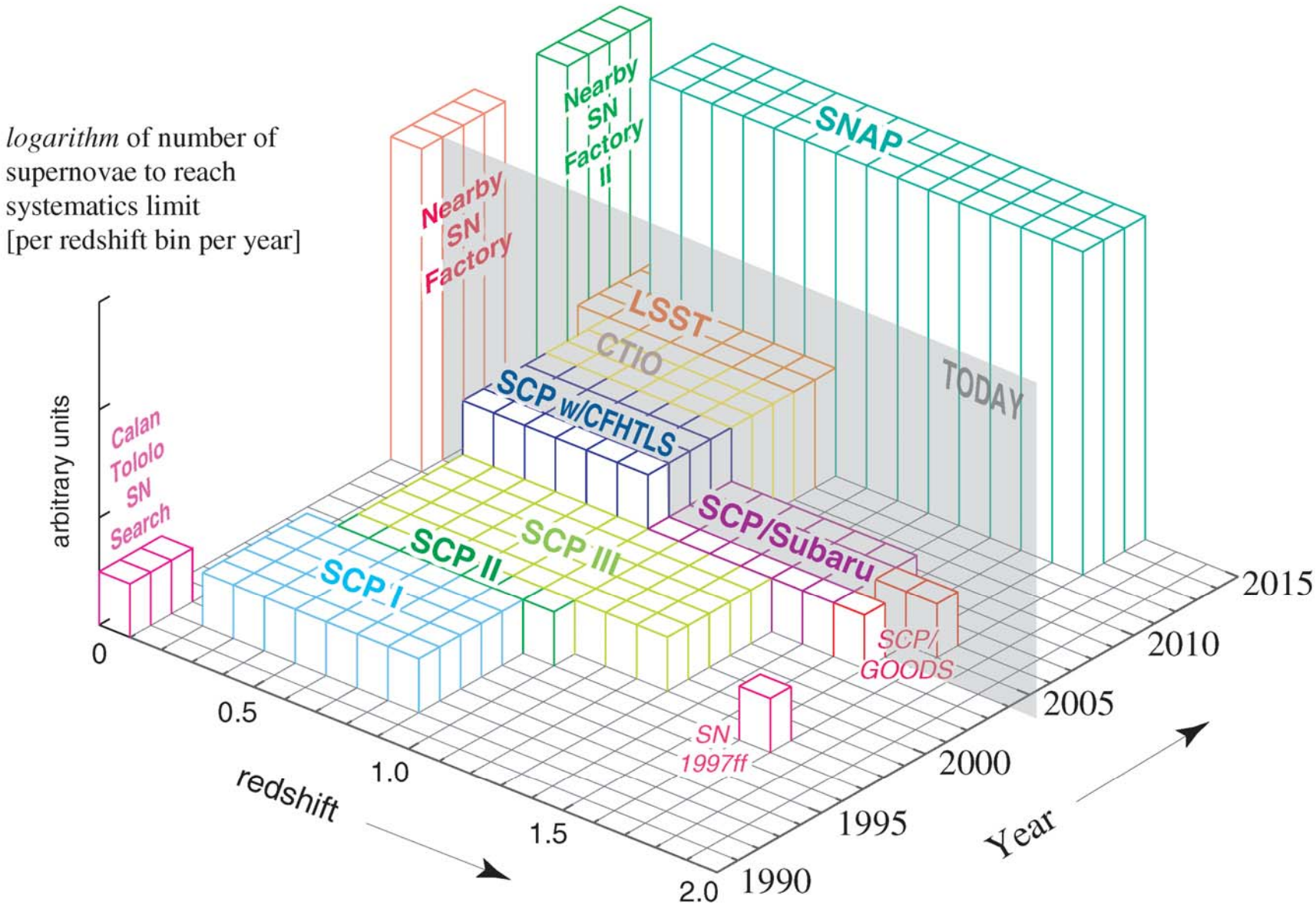
The Context of the Supernova Cosmology Work at LBNL



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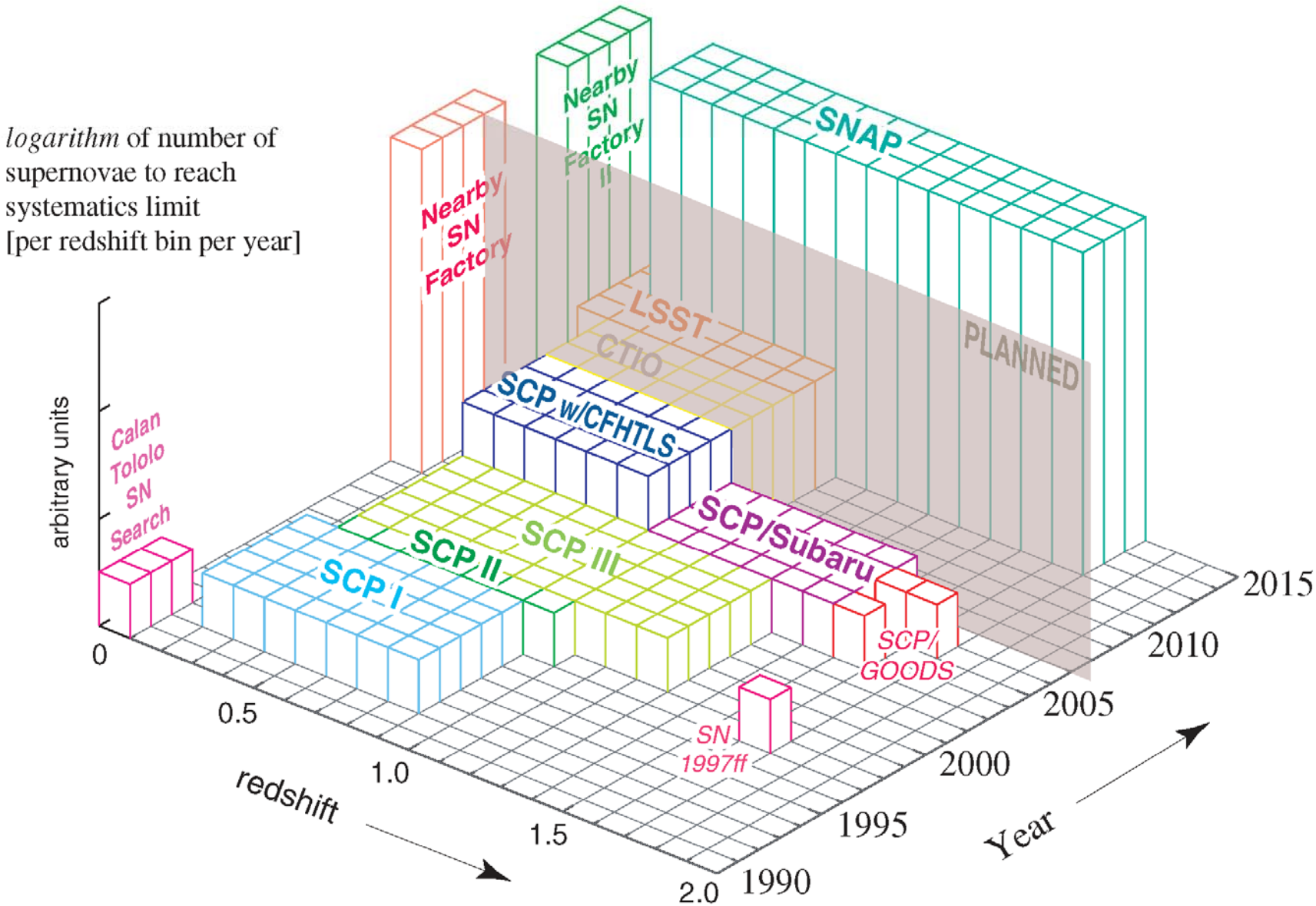
The Context of the Supernova Cosmology Work at LBNL



SCP = Supernova Cosmology Project